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ABSTRACT

This volume contains 41 papers and 6 abstracts/research notes. Titles include: "What makes lessons different? A comparison of a student's behaviour in two science lessons"; "Is achievement in Australian chemistry gender based?"; "Towards becoming a reflective practitioner: what to know and where to find it"; "Sci-Tec: evaluating a non-deficit model of in-service"; "Student understandings of natural selection"; "Development of a hypertext computer program to enhance the scientific writing skills of upper secondary physics students"; "'The approaching storm': ideology, power and control. The National Science Teachers Association curriculum development in the United States"; "Assessing the psychosocial environment of science classes in Catholic secondary schools"; "How can we find out what 3 and 4 year olds think? New approaches to eliciting very young children's understandings in science"; "Developing conceptions of food and nutrition"; "Textbook representations of science-technology relationships"; "The historical context of Newton's Third Law and the teaching of mechanics"; "Effect of context and gender on application of science investigation skills"; "'Hands on - minds on': introducing openness into senior biology practical work"; "Post-primary science teachers' perceptions of primary science education"; "Towards a theoretical basis for students' alternative frameworks in science and for science teaching"; "Teaching problem-solving skills: a reflection on an in-service course for chemistry teachers in Singapore"; "A decade of debate on the schooling of girls in physics: where are we now?"; "Chemical apathy or hysteria: what role for education?"; "Students' understanding of concepts related to plant growth"; "Science teachers' views of professional development"; "Teaching about

theories of light in Year 12 Physics: an historical approach"; "Improving quantitative volumetric analysis skills in first year university chemistry courses"; "A case study of scientific reasoning"; "The relevance of 'recent and relevant' experience"; "Action research through stimulated recall"; "An alternative model for textbook formation"; "How consistently do students use their alternative conceptions?"; "The role of classroom research projects in the preparation of science teachers"; "Facilitating practitioner research into strategies for improving communication in classroom groups: action research and interaction analysis--a reconciliation?"; "Emerging issues concerning the future directions of Australian senior science education: the Queensland experience"; "Conceptions of water-related phenomena"; "A study of force concepts in tertiary level students"; "'The sun is sleeping now': Early learning about light and shadows"; "Response to the Discipline Review of Teacher Education in Mathematics and Science"; "The evolution of an approach for using analogies in teaching and learning science"; "Teacher and student usage of science textbooks"; "Developmental aspects of primary school children's construction of explanations of air pressure: the nature of conceptual change"; "Teaching controversial issues in the secondary school science classroom"; "Teacher perceptions of professional development needs and the implementation of the K-6 Science and Technology syllabus"; and "Taking the plunge into the gene pool: teaching and learning in genetics." (MKR)

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EDITORIAL COMMENTS

The papers in this issue of Research in Science Education are the more tangible outcomes of yet another successful ASERA conference, held for the first time at the Northern Rivers campus of the University of New England in Lismore. (Also for the last time, since the campus is in the process of disamalgamating with UNE at Armidale; it will soon be a separate university, with its own name.) This is an appropriate place to record our thanks to Keith Skamp and his committee for their superb efforts in organising the conference program so effectively.

About 80 papers were presented at the conference; 58 were submitted for publication, and most of these (about 80%) have been published here. As in the past few years, all papers have been independently evaluated by two reviewers, and I would like to express my appreciation to the large number of colleagues (listed on pages viii and ix) for their thoughtful assessments and prompt reviews. Eagle-eyed readers may detect an improvement in printing quality this year. RISE continues to keep in step with the technological revolution: for the first time, the masters have been prepared with a laser printer.

The Lismore conference took an important decision and implemented an idea first raised in Perth in 1990: to develop RISE into a regular journal, with several issues per year. Cam McRobbie of the Queensland University of Technology readily offered to attempt to produce two non-conference issues of RISE in 1994. All of us in ASERA wish him well in this endeavour. The success of this innovation will depend on two factors: the willingness of ASERA members and other science education researchers to use RISE as an outlet for our publications, and the willingness of all subscribers to pay the increased costs of an expanded journal.

In the opening article in the 1993 issue of Studies in Science Education, titled "Getting serious about priorities in science education", Myron Atkin and Jenifer Helms refer to the clamour of clashing claims (my alliterative phrase, not theirs) upon the science curriculum:

> New or revised goals are announced regularly and often. Teach science to improve economic competitiveness. Teach it to help people make wise choices as consumers. Teach it to improve personal health. Teach it to protect the environment. Teach it to help prepare the scientists and engineers the country needs. And above all, whatever the purpose of teaching science in the schools, it should be for all the students.
>
> Each goal seems worthy and is usually embraced by both science education professionals and the public. Then new goals come along. Teach science to foster problem-solving ability? Yes. Teach it to prepare people for jobs? Yes. Teach it to cultivate critical thinking? Yes. These too, are added to the list.

To these American voices, we can easily add some Australian ones. Teach science in the kindergarten and primary school, to encourage early interest. Teach science according to nationally-agreed guidelines, to encourage national cohesion. Teach science in ways that are gender-inclusive. Teach more science to teachers, so that they can teach it better to students.

It is of course possible to view this collection of demands in a positive light. Science education is complex, and it plays an important role in modern society. It is therefore hardly surprising if we find a rich variety of claims for attention on the nation's science curricula. The papers included in this issue of Research in Science Education hold up a mirror which reflects that rich variety. Students' misconceptions in biology. Gender bias in chemistry. Computer usage in science teaching. Science-technology relationships. Science in the kindergarten. Food and nutrition. Science investigation skills. Practical work in biology. In-service courses for teachers. Chemical pollutants. Historical approaches in physics. Reasoning skills. Arguing by analogy. Teaching about controversial issues. These and other themes are all represented in this volume.

However, Atkin and Helms also sound a warning. There are so many different demands upon the curriculum that the public — and science educators, too — are "engulfed by undifferentiated statements of purpose that in their totality are both confusing and unrealistic". One important consequence is that many goals turn out to be impossible or ignored. This may "diminish the credibility of the profession because the public does not know what really to expect, and teachers don't know what to teach". They argue that the science education profession must learn how to identify priorities and to make choices; their essay is an attempt to frame guidelines towards that end. Their long and thoughtful paper contains much that will challenge science education researchers in Australia and New Zealand. Studies of the conflicting pressures on science education curricula in this part of the world, and of the development of approaches to their resolution, might form the basis for future papers in this journal.

Paul Gardner
Editor

Monash University
November, 1993

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Mary Smith & John A. Smith
University of Central Australia Alice Springs College

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Fig. 3 A model of the learning process

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White, R., & Tisher, R. (1986). Natural sciences. In M.C. Wittrock (Ed.) Handbook of research on teaching (3rd ed.) New York: McMillan.

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Research in Science Education, 1993, 23, 1 - 9

WHAT MAKES LESSONS DIFFERENT? A COMPARISON OF A STUDENT'S BEHAVIOUR IN TWO SCIENCE LESSONS

Ken Appleton
University of Central Queensland

ABSTRACT

A fascinating aspect of teaching is that no two days are ever the same. Such variety makes teaching an exciting and interesting profession, but can also generate problems. Apparently small changes in the way two lessons, supposedly similar, are conducted can result in very different lessons. How this occurred for one Year Seven student during two science lessons using discrepant events is explored in this paper. Her responses to each of the lessons were similar in some respects, but quite different in others. Differences between the lessons are examined, and possible reasons for the differences in the student's responses are explored.

INTRODUCTION

Concern has been expressed about the restricting effects of classroom discourse in many lessons which prevents students from asking questions, and formulating their own hypotheses (Barnes, 1976; Biddulph, 1982). It was this concern, amongst others, that motivated Biddulph and Osborne (1984) to suggest an alternative teaching approach for science, the *Interactive Approach*, which included an inherently different form of teacher-student interaction that would allow students to raise questions and formulate hypotheses. Other teaching approaches, such as suggested by Baird and Mitchell (1986), have been proposed for science lessons, which also attempt to encourage students to engage in question-raising and hypothesis formulation. However, is changing the teaching approach and hence the interaction pattern sufficient for students to engage in these behaviours? Fleer and Beasley (1991) would suggest not, but contend that the actual interaction that the teacher engages in with the student is crucial for higher cognitive learning to occur. Another consideration is the student's responses to the teaching approach, interaction pattern, and actual interaction available. To what extent are students' responses to lessons context dependent? This study examines a student's responses in two science lessons that were designed to encourage students to ask their own questions, then propose and test their own hypotheses (Suchman, 1966), and identifies some of the factors which appeared to influence the student's behaviours in the lessons.

THE STUDY

As part of a study of students' responses to teaching approaches in science, two science lessons were observed. The lessons were conducted in a large primary school in a provincial city in Queensland, in a Year Seven class. The same teacher taught both lessons to a small class of about fifteen mixed ability students. Where possible the same students were used. Each lesson was the first lesson of a topic, and essentially followed the procedure suggested by Suchman (1966) for presentation of discrepant events. The lessons were held about three weeks apart.

The teaching approach involved a demonstration designed to present a discrepant event, or puzzling situation which was counter-intuitive. The demonstration was conducted with little explanation or comment. The students were then invited to ask questions about the demonstration and materials. The teacher answered questions with either a "yes" or "no", or repeated the demonstration to provide an answer. Questions which sought the confirmation or rejection of an idea (theory) were not answered, though students could test theories by phrasing questions as thought experiments involving the materials. For example, the question "Does it matter if the lengths of the two pendula are different?" would not be answered, whereas the question "If the second pendulum were half as long, would it be moving in the same way as the first one after three minutes?" would be answered by a "No". Students were free to discuss ideas amongst themselves whenever they wished. Each of the lessons was intended to serve as an introduction to the topic, and would be followed by subsequent lessons. Suchman (1966) insisted that at no time should the teacher confirm or deny a theory, but that the students should decide when an adequate explanation for the demonstration had been arrived at.

Two key differences in teaching approach occurred between the lessons during their implementation. The first was the nature of the discrepant event chosen for the demonstration. The second was whether the students expected the (scientifically) correct answer to be revealed. The first discrepant event was adapted from *The Diving Bottle* (Suchman, 1966). A small glass bottle was upturned in a tall glass cylinder of water, and adjusted so that it only just floated (see Fig. 1). A sheet of rubber was fastened over the top of the cylinder, and pushed gently. The bottle sank to the bottom of the cylinder, and remained there even when the rubber sheet was removed. When the rubber sheet was pulled upwards gently, the bottle rose to the surface. During the lesson, the procedure was repeated with an eye dropper partially filled with water. However, the eye dropper did not sink. At the beginning of the lesson, it was made quite clear that the students would not be told the answer, and would not have theories confirmed.

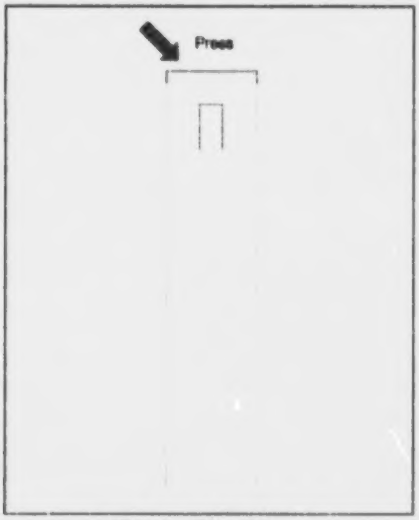

Fig. 1 The Diver

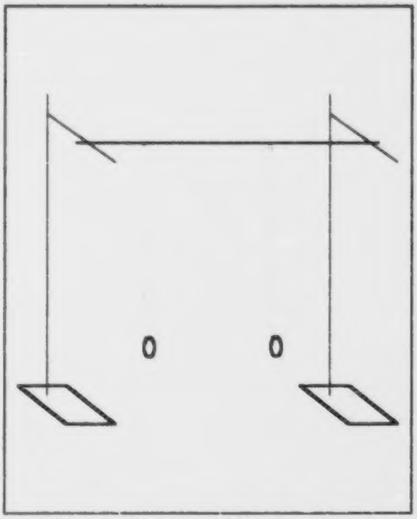

Fig. 2 The Double Pendulum

The second discrepant event was adapted from *The Double Pendulum* (Suchman, 1966). A thin wooden rod was rested across two metal rods supported by stands about seventy centimetres above the desktop (see Fig. 2). Two identical pendula were attached to eyelets fastened to the wooden rod, about twenty centimetres apart. The pendula were made from thick wire about 45 cm long, with hooks bent at the top and bottom. One end on each was hooked through an eyelet, and on each lower hook were placed five metal washers. The teacher started one pendulum swinging. Within a very short time, the second pendulum began swinging. After a few minutes, it was moving with an equivalent amplitude to the first, and shortly afterwards was moving with a greater amplitude, while the amplitude of the first was considerably diminished. Later, during the lesson, pendula of unequal lengths were also tried. When the lesson commenced, the teacher informed the students that, although ideas would be neither confirmed nor denied during the lesson, the correct answer would be given at the end. This latter difference was not planned for, but was a consequence of the teacher's adaptation of the teaching approach in line with her preference for lesson closure.

The students were seated in groups of four, all facing the teacher. Both the teacher and one group of students were observed during the lessons.

DATA COLLECTION AND ANALYSIS

The two lessons were videotaped, and the students in the group observed were interviewed after each lesson, using the videotape to stimulate their recall of what was going through their minds during the lesson. Such stimulated recall techniques have successfully been used in other studies (Edwards & Marland, 1981, 1984; Peterson & Swing, 1982; Peterson, Swing, Braverman & Buss, 1982). For the purposes of this report, the data for one student, Melinda, are presented. The interviews were transcribed and the student's statements were categorised using a descriptive system of student responses developed inductively from the data in the larger study. The videotapes were also viewed and observed student behaviours were categorised and added to the description of the student's responses obtained from the interviews. The combined data were used to compile a description of the student's responses during each lesson. Responses examined were cognitive responses, including the level of cognitive conflict arising from the discrepant event, affective responses, and strategies used to cope with the demands of the lesson and social context. As well, the frequency of selected student responses was obtained from the videotaped lessons. Differences in Melinda's responses between the lessons were identified, and the interview transcript and videotaped lesson were used to identify possible reasons for the differences.

MELINDA'S RESPONSES DURING THE LESSONS

Table 1 allows comparison of Melinda's responses during both lessons. It shows only those responses observed during the lesson, and does not indicate sequence or frequency. It can be seen that there are many similarities, but some differences. Key differences identified are:

- A low level of cognitive conflict was present in the second lesson compared to the first.
- Coping strategies such as waiting for information to be provided by the teacher and engaging in play and humour to maintain a social image, were present in the second lesson but not the first.
- There were six cognitive responses which were present in the first lesson, but not the second.
- Three affects related to the demonstration/materials were present in the first lesson, but not the second; and three related to the social context were present in the second, but not the first.

A noticeable difference in Melinda's responses between the lessons was her use of humour. In the 36 minutes of the first lesson, Melinda made eight jokes. The second lesson was appreciably shorter, but in its eighteen minutes Melinda made 39 jokes, in contrast to the four jokes per eighteen minutes in the first lesson. Given this difference in level of humour and other differences in cognitive responses and coping strategies noted above, Melinda's overall cognitive response to the first lesson was at a higher cognitive level than was her response to the second lesson. As well, her affective responses in the first lesson were, from a teacher's point of view, more appropriate than those in the second lesson. Further, the coping strategies she used in the first lesson tended to be more cognitively oriented to finding a solution to the demonstrated discrepant event than were those in the second lesson.

POSSIBLE INFLUENCES ON MELINDA'S RESPONSES

Melinda's responses to the two lessons therefore stood in sharp contrast to one another. Possible causes for such different responses were examined. Two key observed differences between the lessons, the discrepant event used to initiate the lessons and whether the teacher would provide an answer, may have had a causal effect on Melinda's behaviour.

Other possible behavioural influences can be conjectured, such as Melinda's mood on each of the days of the lessons, differences in behaviour by her peers, and differences in the teacher's mood. Further data were sought from the videotaped lessons and interviews to illuminate these aspects. The possible influences on her behaviour are examined below.

Possible differences in Melinda's mood between lessons.

While this cannot be eliminated as an influence on Melinda's behaviour, there was nothing in the interviews or on the videotapes to suggest that Melinda was upset, tired, or ill. Both lessons occurred at about 9.30 am (three weeks apart), so time of day was not a factor.

TABLE 1
COMPARISON OF MELINDA'S RESPONSES DURING THE LESSONS

Melinda's Responses	**Diver Lesson**	**Double Pendulum Lesson**
Cognitive Conflict	High level, changing to low level during the lesson.	Low level throughout the lesson.
Coping Strategies - related to a cognitive response.	Postulating about variables and/or explanatory theories. Seeking confirmation that an idea is correct. Sharing an idea during discussion in a small group or whole class. Using or taking up another's idea.	Postulating about variables and/or explanatory theories. Seeking confirmation that an idea is correct. Sharing an idea during discussion in a small group or whole class. Using or taking up another's idea.
- relief of stress arising from a demanding or boring lesson.	Making humorous comments about the work. Trying to attract the teacher's attention.	Making humorous comments about the work. Trying to attract the teacher's attention.
- personal response to a lesson context.		Waiting for information to be provided.
- related to a social relationship.		Engaging in play and humour to maintain a social image.

Melinda's Responses	Diver Lesson	Double Pendulum Lesson
Cognitive Responses - a remembered idea is used or sought.	Recognising that no explanatory ideas come to mind. Attempting to think of a reason to account for something. A tentative idea to explain the event. Observing a "new" aspect of the event not noted previously. Evaluating an idea in the light of new information. Linking an aspect of the event or discussion to previous experience/ ideas. A developed and fuller idea to explain the event. Confident that an idea is correct. Aware that an idea is incomplete with aspects unresolved.	Recognising that no explanatory ideas come to mind (later in lesson). A tentative idea to explain the event. Observing a "new" aspect of the event not noted previously. Evaluating an idea in the light of new information. A developed and fuller idea to explain the event. Confident that an idea is correct.
- information is sought from the materials.	Attempting to identify conditions relating to the event. A thought experiment to test conditions.	Attempting to identify conditions relating to the event. A thought experiment to test conditions.
- a verbal response in a social context.	Thinking of a question to ask. Attempting to phrase a question for a yes/ no answer. Explaining to others an idea, prediction or observation.	Thinking of a question to ask. Explaining to others an idea, prediction or observation.
- information is received from a social context.	Listening and trying to understand another. Comparing or contrasting others' ideas with one's own. Relating information provided to one's own ideas to reach understanding. Another's idea triggers a new line of thought.	Listening and trying to understand another. Another's idea triggers a new line of thought.
Affective Responses - affects related to the materials/ event.	Curiosity generated from a puzzling situation. Frustration at not knowing the answer. The challenge of thinking of an answer. Enjoying the lesson or a part of it. The lesson or a part of it was interesting.	Curiosity generated from a puzzling situation (later in the lesson). The lesson or a part of it was interesting.
- affects related to the social context.		A social aspect of the lesson resulted in boredom. Enjoying off-task play or showing off. Frustration resulting from a social aspect of the lesson.

(Table 1 continued)

Differences in behaviour by her peers.
For each lesson, Melinda was seated in a group of four. The group membership differed slightly between lessons because of absenteeism. In the diver lesson, group interaction was mainly task oriented. Even the occasional humorous comment was task-related. In the double pendulum lesson, group interaction was usually task-oriented. Many of Melinda's humorous comments were made to any one who might be listening, rather than to the group. There was nothing in the behaviour of the groups which appeared to be an influence on Melinda's behaviour.

Possible differences in the teacher's mood between lessons.

Discussions with the teacher prior to and after the lessons did not reveal any discernible differences in the disposition of the teacher. Apart from some initial nervousness in the first lesson, the teacher's manner during the lessons was also consistent. Therefore, while differences in the teacher's mood between lessons cannot be eliminated as influences on Melinda's responses, it would seem an unlikely cause.

Differences in the type of discrepant event.

It is likely that the diver and double pendulum discrepant events were different in their level of complexity and challenge. In interviews held after all the lessons, many students commented that the diver lesson was more challenging.

Furthermore, the diver in the first lesson was a totally new experience for Melinda, whereas the double pendulum was not. She had seen a double pendulum working during a recent visit to an interactive Science Centre, and had also seen one when visiting a local secondary school. However, she did not know how the double pendulum worked. This accounts for the difference in the level of cognitive conflict between the lessons. Suchman (1966) suggested that discrepant events serve as strong motivators for students to work towards a solution to the event. A lack of initial motivation in the double pendulum lesson resulted in Melinda taking some time before she became interested in trying to find a solution:

> Well we'd seen it before, so we sort of weren't, I wasn't really sort of too interested...I sort of wondered why it was doing that a little later, but at the beginning I'd seen it before so I wasn't really - it wasn't something exciting.

Melinda became interested when other students began making observations, asking questions and proposing theories about the double pendulum, and began working towards trying to find a solution.

Differences in expectations about the lessons.

Melinda knew the teacher would provide an answer at the conclusion of the double pendulum lesson, whereas she knew she would not be given an answer in the diver lesson. This emerged as a major influence on her behaviour. Her preferred way of working in science lessons was:

> I like being able to do things. Find out new things...I like being able to sort of being able to work things out.

During the diver lesson, this is what she did, within the constraints of the lesson. She enjoyed the challenge of working on ideas, even though they did not always work out:

> It's fun to be able to sort of talk about what you think yourself instead of listening to the teacher tell you the answer right away, but it's fun to sort of work it out in your own mind...we couldn't think of anything why and it was just hard because there were so many ideas that we thought of and none of them sort of were right. They all had one thing wrong with them that made them wrong.

Humour had a place in this lesson, but it was controlled and task-related:

> sometimes when we would run out of questions...we'd get bored of it so we'd just go "You must be magic. Maybe you have a magnet on the bottom or something that's pulling it." ...but while we were doing that we were still thinking what else could it be that was sensible.

Humour, then, was used to relieve the cognitive tension of trying to arrive at a solution when no obvious answers were apparent in this lesson. In contrast, her comments about the double pendulum lesson show that she also used humour to relieve boredom while she waited for the answer to be provided:

> I sort of said [during the lesson], "It's not our fault that we're wrong, we need teachers to teach us." 'Cause we were sort of getting a bit frustrated, a bit bored because I guess we couldn't really find out whether we were right or wrong...I couldn't think of [any better theory] so I was just sort of waiting until the teacher finished so we could find out whether we were right or wrong...I guess maybe if I'd tried I could've thought of something to get out of it a bit better, but I was sort of more waiting. That's the easiest way.

When asked why she engaged in humour during the lesson, she explained:

> I guess it's sort of something to do, something to make us laugh, to sort of enjoy it a bit more.

During interviews with other students after the lesson, they were asked about Melinda's jokes. It emerged that Melinda frequently made humorous comments during lessons. In other lessons observed informally during visits to the school, Melinda was observed making similar humorous comments. They were made in a non-disruptive manner, and seemed to be accepted by students and teachers as appropriate ways of relieving the boredom of concentrating on a task.

DISCUSSION

It seems that Melinda has an accepted role of "joker" during lessons, such behaviour designed to relieve boredom from necessary but tedious tasks. This role was assumed infrequently in the diver lesson, but was used extensively in the double pendulum lesson. Most everyday lessons taken by the teacher seem to be convergent, with definite closure at the end of the lesson. It is likely then, that Melinda has developed her joker role as a learned response to cope with lessons which are, to her, tedious. She therefore uses humour in lessons to provide relief from tedious lessons, and to maintain her social image as joker. The double pendulum lesson apparently was sufficiently similar to everyday lessons to trigger this response. The diver lesson, in contrast, was open-ended. Humour in this lesson was used to relieve cognitive tension rather than boredom.

The work of Biggs (1987; Biggs & Moore, 1993) sheds some light on Melinda's behaviour in these lessons. He described three approaches to learning in tertiary and secondary students: the surface approach, deep approach and achieving approach. Students who use the surface approach try to avoid both working too hard, and failing in assessments. The main strategy employed is rote learning, where students focus on what appear to be the important points, and try to reproduce them. Those who use the deep approach are intrinsically motivated, and are interested in the task. They use strategies to help them understand the task, such as trying to relate it to what they already know, and deriving hypotheses to explain it. The motivation for students using the achieving approach comes from "the ego trip that comes from achieving high marks" (Biggs & Moore, 1993, p. 313). They choose strategies which will give the best rewards from the teacher and the highest marks, so strategies will vary depending on the task and situation. There is always an element of efficiency in their choice, which can involve either deep or surface approaches.

The data in Table 1 for the diver lesson show comparable behaviours to those for the deep approach. This would suggest that Melinda's preferred learning approach is the deep approach, and she is motivated by a desire to understand the task at hand. Since she was also very concerned about verifying her answer and ensuring the answer arrived at was correct, it appears that she is also strongly achievement-oriented. Therefore, in the diver lesson, because the teacher had said that the answer would not be forthcoming, Melinda chose to use deep approaches. The combination of the different interaction pattern of the lesson, a highly motivating discrepant event, and Melinda's use of deep approaches made the lesson very different from everyday lessons, so the use of humour formed a minor part of the lesson. However, in the double pendulum lesson, with the assurance that the answer would be eventually provided, Melinda chose to use a minimum of deep processing, and some surface processing. For her, this was the most efficient way to satisfy both her need to understand the task and her desire to achieve, with a minimum of effort. Even though the interaction pattern of the lesson was different from everyday lessons, the combination of low motivation from the discrepant event and Melinda's choice to use a minimum of deep processing resulted in a lesson where humour was necessary to relieve the tedium of waiting for the answer.

Melinda's behaviour in these lessons highlights the contention by Biggs (1987) that achieving-oriented students will choose the most appropriate learning strategies for the context. That is, Melinda's behaviour was context dependent. The contrast in Melinda's behaviour between lessons also highlights the powerful effect that students' expectations about the lesson can have on their behaviour in a lesson. Melinda was motivated to succeed in both lessons, but her choices of how to achieve success were dramatically different. Her choices were determined by the level of cognitive arousal from the initiating demonstration, and whether the answer would be provided by the teacher. The latter issue raises serious questions as to whether the apparently common expectation among teachers and students that the "right" answer be provided during a lesson, is compatible with goals such as formulating hypotheses and open-mindedness.

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IS ACHIEVEMENT IN AUSTRALIAN CHEMISTRY GENDER BASED?

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ABSTRACT

This paper compares the performances of female and male secondary students in the 1991 and 1992 Australian National Chemistry Quizzes. Male students consistently achieved a higher mean score in all Year groups (7 to 12), even though the numbers of female and male entrants were approximately equal. Implications for class tests and assessment tasks are addressed.

INTRODUCTION

The Royal Australian Chemical Institute introduced a National Chemistry Quiz in 1982, with two papers: a Senior Paper (Years 11 and 12) and a Junior Paper. A third paper (Years 7 and 8) was introduced in 1989, and a separate paper for Year 11 in 1992. The number of students taking the Quiz has increased from 8,750 (150 schools) in 1982, to over 63,500 (850 schools) in 1992. Schools from all Australian states, Fiji, New Zealand and Papua New Guinea participate.

The Quiz aims to encourage a better understanding of the nature of chemistry and its relevance to society. Some of the items specifically relate to chemistry in everyday living. Each paper in the Quiz is non-syllabus based and contains thirty multiple choice questions designed to stimulate interest in chemistry. Items have been classified (based on Bloom's 1956 Taxonomy of cognitive objectives) into knowledge; comprehension; application; and analysis categories (see the two books of past papers by Beard, Fogliani, Owens, & Wilson, 1992a, 1992b). In the 1991 Quiz for Years 11 and 12, the percentages of questions in each category were: knowledge 17%, comprehension 23%, application 43%, and analysis 17% respectively. A high standard is demanded by the Quiz; less than 130 students scored 29 or 30 out of 30 in 1991 and 1992. No penalty is applied for incorrect answers and various awards are given for levels of achievement.

The main aim of this paper is to report and to compare the performances of male and female students in the 1991 and 1992 Quizzes.

RESULTS

The numbers of males and females entering the Quiz are approximately equal. The numbers of students entering increases by the year level (3,000 in Year 7 to 12,350 in Year 12). About a thousand fewer females than males in Year 12 and 500 fewer in Year 11 participated in the Quiz in 1991 and 1992. In contrast, more females than males in Years 7-10 participated. However, there were approximately twice as many males as females for each Year group in the top 150 students. The ratio of male:female ranged, across the Years, from 1.8 to 3.4 in 1991 and from 1.5 to 5.3 in 1992.

Overall, males performed better than females with the mean scores for males ranging from 0.47 to 2.01 marks above the females' mean scores (standard deviations were around 4). For each Year the mean scores for males and females were significantly different at the 0.001 level except for Year 7 in 1992 where the level of significance was 0.01 (using a t-test analysis).

For each of Years 7-12, a higher percentage of males gave correct answers for the majority of questions, increasing from 18 out of 30 items in Year 7 (for 1992) to 28 out of 30 items in Year 12.

Males often performed better in questions involving the interpretation of graphs and, for four of the five questions used in more than one year level, the differences between the performances of males and females widened as the year level increased.

In the Year 12 1992 paper, the percentage of males selecting the correct answer exceeded the percentage of females by more than 10% in six questions. Four of these six questions required chemical calculations to be performed. (A total of 12 questions out of 30 involved calculations.) The differences in percentages of males with the correct answer to females with the correct answer ranged from 11% to 14%. A higher percentage of females than males gave the correct answers to two questions but the differences were much lower (3% and 4%). One of these questioned was concerned with "the effect of a catalyst on an isolated chemical reaction" and the other involved the completion of a flow chart on the preparation of ammonium sulphate.

A similar situation exists with the results of male and female students in Years 7-11. For the questions that either gender answered more successfully, the difference in the numbers of items and in the percentages of those correct to not correct are generally in the males' favour. The differences for Years 7 and 8 are not as great as for the other four year levels.

Overall, for Year 12 in 1992, the difference between males and females omitting items is small. More males than females omitted 5 of the questions whereas more females omitted 20 of the items and for the remaining 5 items, the omission rate was the same. The average difference in percentages of omission was 0.3%. The item most omitted was a calculation question which almost 5% of students omitted. For this item, 0.7% more females than males refrained from answering.

DISCUSSION

The finding in this study that males perform consistently better than females in chemistry in Years 7 - 12 is supported by two other major recent studies (Rae, 1993; Rosier, 1988). Rosier commented on the achievement of Australian lower secondary students (14 year olds, about Year 9) in the Second International Science Study (SISS). Male students scored a mean of 59.8% and female students 56.0%. There was a significant difference at the 95% confidence level. On the 15 chemistry items, the mean scores were 49.5% and 46.1% respectively with a significant difference at the 95% confidence level. Rosier noted that the better performance by male students in the SISS was significant on questions requiring comprehension and application but not knowledge.

Rae (1993) analysed Victorian Higher School Certificate chemistry examinations from 1987-1990 and found that the male cohort made more correct responses in multiple choice items. In addition on several items in each examination "the success rate for male students exceeded that for female students by 10% or more". Almost half of these items involved chemical calculations.

Alternative explanations for gender differences

It cannot be said conclusively from these results that males perform better in chemistry than females because the sample, though large, was self selected and because the Quiz format may have been gender biased.

The samples of males and females taking the Quiz were not random or equivalent as only some schools out of the total national school sample are involved in any year, and most schools do not enter all their students studying chemistry. The proportion of females studying public examination chemistry in Year 12 in Australia in 1990 was 17,530 out of 40,597 students, i.e. 43.2% (Dekkers & De Laeter, 1993). The 5,412 females who participated in the 1991 Quiz represent about 30% of the females in Year 12 studying chemistry.

Format and content of the Quiz

The format of the Quiz may favour male over female students who sit for multiple choice tests/examinations (Murphy, 1978; Harding, 1979; Rennie & Parker, 1991; Woolnough & Cameron, 1991). Murphy (1978) mentioned the possibility that "the attitude of females to objective tests is low". Rennie and Parker (1991) suggest that item and test formats plus item context are very likely to be involved in the explanation of the females' lower performance in multiple choice questions.

Although attempts were made to minimise the effects of item context, there were two examples in the 1992 Quiz which may favour males. Question 12 (Year 12) was about moles and involved "a stone about the size of a cricket ball" while question 12 (Years 7 & 8) related to metals "used in alloys such as solder and bronze".

Another factor which may have contributed to the difference in performance is "males' greater willingness to guess" rather than to omit items in multiple choice tests (Rennie & Parker, 1991). However, the differences were slight in this study. Boys often show a confident assurance and are less inhibited about guessing when they are not certain of the correct answer. The use of guessing by males in the Australian National Mathematics Competition has also been noted (Clements, personal communication, 1993) but in this Competition, there is a penalty for guessing.

Mathematics and science

Gender differences in mathematical ability have been proposed by many researchers but there is "normally more variations in these skills within groups of males or females than there ever is between them" (Murphy, 1978). In the United Kingdom, the areas of mathematics showing the greatest gender differences are application of number, measurement, rate and ratio, concepts of fractions and decimals, and computations with fractions (Shuard, 1986). Gardner (1974) concluded that girls did not perform as well as boys "on tests measuring numerical skills, mathematical reasoning and formal operational thinking".

The mathematical skills required to answer the questions in the Quiz include facility with percentages, fractions, logarithms to base 10, addition, division and finally ratio and proportion. No advanced mathematical ability is required to answer almost all multiple choice questions except for one or two questions in Years 11 and 12. However in the 1992 Year 12 paper, four out of the six questions in which the average percentage of males correct exceeded the average percentage of females correct by at least 10% involved chemical calculations.

Gardner (1974), Head (1985), Sjoberg (1990) and others have suggested that biological, environmental and social aspects of science or chemistry would be more interesting to females and hence one would expect they might perform better on such questions. In fact girls in Years 7-12 performed less well than boys on questions which emphasized these aspects in both the 1991 and 1992 Quizzes. The results on 45 such questions given to Years 7-12 show boys did better than girls on 34 questions while girls out-performed boys on 11 questions. Of the 16 questions on biological, environmental and social aspects of science given to Years 11 and 12, ten involved mathematical calculations and the boys performed better in all ten cases.

In-school and out-of-school experiences
Some researchers including Yates (cited in Jones, 1993) still claim that the school curriculum is biased towards the interests of males and that inequality is quite widespread. The school attended is an important factor in students' performance but there is conflicting evidence on whether single-sex schools or single-sex classes in mathematics and science is the best environment for females.

Gardner (1974) evaluated many studies of secondary students' interests in science and concluded there is "a substantial body of evidence showing that boys display more interest in science than girls". This may no longer be correct in 1993 given the increase in the number of females studying science subjects to Year 12 although more males participated in the Chemistry Quiz than females. However boys may still be more interested in physics. Gardner noted that boys engage in tinkering more frequently than girls with mechanical and electrical objects. Tinkering outside of school such as repairing equipment, was identified by Gardner as showing the highest correlation with gender differences in performance in science subjects.

Rennie and Parker (1991) related the different out-of-school experiences for males and females with their different performances in science subjects. Males will perform better in areas where they are more familiar with the context. Hence in both chemistry and physics males often have an advantage.

IMPLICATIONS FOR STUDENT EVALUATION

Teachers at all levels of the education process should be aware that the exclusive or extensive use of multiple choice questions in assessment for chemistry and other science subjects might advantage male students. If multiple choice questions are balanced by structured questions and essay questions, then girls are less likely to be disadvantaged (Harding, 1979 and Rennie & Parker, 1991).

Also it is difficult to test Bloom's (1956) higher categories of "synthesis" and "evaluation" using only multiple choice questions. Some academics and teachers use multiple choice question extensively in the evaluation of students because the answers can be easily marked. It would be interesting to compare male and female students' performance on practical work, course work and a final examination that consisted of multiple choice questions.

CONCLUSION

Gender differences in science were first noted in the 1970s. It may be thought that with the greater encouragement given to girls to undertake chemistry subjects, with attempts at gender equity in schools and the community, and with more females continuing on with chemistry at senior years of school and at university, that there may now be a change in the achievement of females in chemistry compared to that of males. However, this large study would indicate that females are not performing as well as males in chemistry although there are several possible alternative explanations for the results obtained in the study.

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TOWARDS BECOMING A REFLECTIVE PRACTITIONER: WHAT TO KNOW AND WHERE TO FIND IT

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ABSTRACT

Preparing student teachers to teach thoughtfully and to consider carefully the consequences of their work involves creating opportunities for these beginning teachers to learn the skills and attitudes required for reflective practice. The case study described here explores one model of developing reflective practice and the congruent role that the source and use of knowledge of good teaching practice has in the process of developing the reflective practices of a post-graduate pre-service science teacher. Of particular interest are the facilitators and barriers she sees as affecting this development.

INTRODUCTION

Despite apparent overwhelming support in the literature during the last decade for the development of reflective practices in preservice teachers, the definition and description of the key concept, reflection, remains quite open. While the overlap between many authors' ideas and perceptions is often considerable, there are also several discernible differences. These differences, in turn, have led to a multiplicity of recommendations as to the most effective and appropriate form that preservice teacher education aiming towards the development of reflective practices should take.

Grimmet, Erikson, MacKinnon and Rieken (1990) present a functional review of reflective practices with what they see as three pervading orientations or perspectives to reflection in the literature. Their initial pragmatic use of the definition of reflection as "how educators make sense of the phenomena of experiences that puzzle or perplex them" lays the foundation for the rest of their review.

By focussing on how and what knowledge (of good teachers and good teaching practice) is accessed and subsequently used, they build a useful and tangible framework for analysing both current reflective practices of teachers and the practices of teacher educators with respect to the development of reflective practices in their students.

They maintain that their definition of reflection can be developed further by exploring the use of the knowledge base needed for "...making sense of the phenomena...". Thus, by examining the process of utilisation of that knowledge, they present what they see as three orientations to reflection in the literature.

At the least complex level of reflective practice, they maintain, knowledge from external (research) sources drives practice with the emphasis lying with the replication of desirable teacher behaviours (Cruikshank, 1987).

A second, more complex level of reflection suggests that knowledge of good teaching practice is derived from several available and competing sources, with choices by the practitioner being made in the context of practice as to the best course of action. Thus knowledge informs practice.

The third level suggests that new understandings are reached as the practitioner "...recasts, reframes and...reconstitutes..." (Schon, 1987 in Grimmet et al., 1991) understandings in such a way as to "generate fresh appreciations of the puzzlement or surprise inherent in a practical situation." Schon (1987) actually spoke of reflective practice as "the manner in which practitioners frame and reframe problematic situations to make sense of the experiences that puzzle and perplex them".

This process allows teachers to arrive at new understandings of their own practice and thus allows a continual growth in the knowledge of their practice. The emphasis lies with the important theories relating to successful practice being implicit within and growing from the individual's practice itself.

The central premise explored here then, is that as a student practitioner develops from a simple level of reflective practice to a more complex level of such practice, there is a concurrent shift in the perception of that student as to the source and subsequent use of knowledge of good teaching practices.

METHOD

In order to explore this premise, five questions were addressed:

- What change has occurred in the nature of the student's knowledge of good teaching practices and good teachers?
- What shift has occurred in the student teacher's perception as to the source and subsequent use of knowledge about good teaching and good teachers?
- What change has occurred in the student's reflective practice over a specified time?
- What are the factors affecting, the conditions facilitating and/or the barriers inhibiting any changes which may have occurred?
- What events may have influenced the nature of her reflective practice?

As this research was concerned with changes in a student teacher's perceptions of her source of knowledge (of good teaching and good teachers), the use of that knowledge, and changes in her approach to reflection, a methodological approach which relied on interpreting her current perceptions and beliefs seemed most appropriate.

To make it possible to obtain adequate data for any such interpretive analysis, it was necessary to use methods that allowed the student every opportunity to express her beliefs about good teaching, the source of her knowledge and about various aspects of her teaching practice over an extended period of time.

Hence a case study of a preservice part-time post-graduate student, Jane, was undertaken. This study spanned her two year course. Throughout the period of this study, Jane was also working full-time as a medical research assistant. Data concerning her reflective practices was collected at the beginning of her course, at regular intervals throughout her course of study and at the end of the period of observation which coincided with the end of her course of study. Apart from attending her formal lectures during this time, she was also involved in two four week practical teaching sessions in a secondary school.

Jane was selected for a variety of reasons such as her accessibility, her willingness to participate in this project and her role as a preservice post-graduate student. The main reason, however, that she was selected as the subject of this study was because of her previously demonstrated ability to articulate clearly her feelings, her perceptions and many of the her cognitive processes.

The data relating to the student's perceptions of her source of knowledge of good teaching practice were gathered using a variety of methods. Because this research is concerned with the "significance of actions and behaviours" (Erikson, 1986) of a student teacher, it was important to collect data that reflected the points of view of the participant herself. It is important because "humans create meaningful interpretations of the physical and behavioural objects that surround them" (Erikson, 1986). Therefore any methods selected had to focus directly on the participant, the "actor", and her perceptions of her world.

Three types of interviews were applied. Firstly, interviews with a general guide and then subsequently, standardised open-ended interviews were used. There were periods of reflection between each episode which allowed for analysis and interpretation of the data. In addition to this, further detail was obtained from a free-write reflective writing opportunity given to Jane half way through her course of study. The third style of interview was undertaken in order to collect a greater breadth and hopefully depth of information on the processes under consideration. Jane was shown a series of videos of contrasting teaching styles in science classrooms and was asked to comment on these, describing the aspects of the teaching she liked and disliked, and how she would cope with similar material and situations. This task is based on research by Calderhead and Robson (1991) and is aimed at encouraging Jane to make more explicit the taken-for-granted assumptions about her knowledge of good teaching practice. Details of the data collection process are shown in Table 1.

An interpretive research method was used in order to interpret the range of qualitative data that was collected from this study. This method, Erikson (1986) argues, is most appropriate for the "identification of specific causal linkages ... and the development of new theories about causes and other influences on the patterns that are identified in the survey data...".

Thus the findings are presented in the form of a number of assertions derived from the data. Assertions are designed to function as key linkages, as constructs which tie up the "various strings" in the data and demonstrate the plausibility of the objective of the research.

TABLE 1
SCHEDULE OF INTERVIEWS OVER THE TWO YEAR PERIOD

DATE	NATURE OF DATA COLLECTION
July 1991	structured interview
July 1991	video viewing + general guided interview
April 1992	structured interview
April 1992	4 week practice school
May 1992	open-ended interview
June 1992	writing exercise
February 1993	structured interview
April 1993	4 week practice school
April 1993	general guided interview
June 1993	open-ended interview

The framework suggested by Grimmet et al. (1990) for classifying the level of reflective practice of the student was adhered to as closely as possible. Thus the focus throughout remained with where the student perceived her knowledge of good teaching practices to come from and how it was to be used in her own practice. It is the analysis of this accessing and use of knowledge which provided clues as to the nature of reflection which is being practised.

ASSERTION 1: A change has occurred in the nature of the knowledge (of good teaching practices) that Jane considers to be important.

By referring to expert and novice teachers when working in the area of reflective practice, Berliner (1986) suggested that the networks of knowledge and meanings of experts (experienced teachers) are more complex than those of novices. This is because they include more categories, more detail and more interconnections than do the lesser novice networks. He suggests that when confronted with a problem situation (in a classroom) experts can draw on this rich source of previously "acquired, learned and developed" patterns and knowledge and thus make more "appropriate choices and decisions". This, in turn, assists in the continuing development of the complexity of the networks - a spiralling process.

Reynolds (1992) also distinguishes between what she calls competent and novice teachers on the basis of their ability to reflect on unsuccessful classroom behaviours. Not only was the skill of reflection less honed in the novice group she studied, but their concerns and the priorities they placed on what they felt was important to know differed from the competent teachers.

In July, 1991, Jane was preoccupied with two aspects of her practice, namely, "...how to control them..." and what she called "practical knowledge" of the subject she was to teach (chemistry). "Teaching", she believed, "is about explaining well... and the subject matter is most important". Also, "I need a good list of discipline methods that works". She does make a passing mention of the desirability of "making a relaxed classroom environment...".
One session of practice school and ten months of her course, however, and a note of desperation entered her discourse. Phrases like "...surviving and coping..." and "...just how will I deal with all I have to know..." as well as "...there's so much more involved than I thought..." (April 1992) surfaced, indicating a shift in her original ideas about both the breadth and the nature of what she felt she needed to know. The "prac school nightmare" opened her eyes to a "whole range of things ... I hope I can find out about before I go back there..." (February 1993).

By June 1993, after that second session and further lecture courses, some of the elements of Reynolds' competent teacher began to emerge in phrases such as "...I have to be ... finding out what is relevant to my kids..." and "..I need to be able to know how to anticipate what is happening in my classroom...". Students had obviously shaped up in her mind as individuals with needs that she felt she had to assist to meet, "...I must know how to meet their needs for when they leave school...". Her perception of the nature of her subject matter itself was also shifting in this period of time: "I used to think chemistry, science really, was what they gave us in lectures at Uni - it's nothing like that really is it? How on earth can I find out what I should be teaching as science in my classes?" (July 1991). But by June 1992, a different note was emerging.

> I've never read as many newspapers as I have in the last six months ... it takes so much time to keep up with everything in the world so I can make my grade nine's understand that science is not a dead subject ... that it has relevance for them ...and ironically me too ... I had never really thought about it myself until I had to face survival by being interesting or DIE (her emphasis).

Of course, how to handle "sanity, survival and stress" were still issues uppermost in her mind. But the focus on her classroom strategies had shifted from "discipline" and "punishment" (July 1991) to "management" of time, people and curriculum (June 1993). "I need to know how to make them all work the best way I can."

ASSERTION 2: A change has occurred in the source of knowledge (of good teaching practices) that Jane considers to be important.

Calderhead (1987) in his review of existing theoretical frameworks concludes that the "student teacher, in learning how to teach, has to cope with a wide range of differing experiences... thus the necessary knowledge developed by the student will vary over time in content, nature and ...how and where it is acquired".

It all seemed so clear-cut in July, 1991: "I'll learn how to teach from here (QUT)... the lecturers should be able to tell us how to teach." In a sense, this was a surprising admission, as Jane had worked for a number of years and could have been expected to have drawn on many different sources for her knowledge of good practices as she indicated she would normally do at work. A little prompting yielded "I think I would like to see some really good teachers at work". But, at this point "good" was strongly linked to "well disciplined" and "good grasp of subject matter".

Once again, practice school seemed to challenge her preconceptions and shake her confidence in what she called "the formula for successful teaching". In April, 1992 Jane was saying "I'm not so sure anymore ... everyone tells you something different ... and I keep trying to remember what the teachers I thought were good would have done ...". By June of the same year, "... I just hadn't realised ... how important a role my preconceptions and experiences would play in my own classroom behaviour, especially when I would get stressed and forget what I had been told at College". There was a real note of desperation evident in her words just prior to the second practice session "...I've run out of places to go for help - the apathy of some teachers is appalling...".

It was not until after this session that a new note of confidence in her own ability to decide on a course of action surfaced (June, 1993): "some days, after a particularly bad one, when my supervisor just shrugs as if he doesn't care, I go home, tear up a few pillow cases with my bare teeth and then get down to the business of sorting it all out. Otherwise, tomorrow will be just as bad ... and I don't have that many pillowcases...".

With this came a decreasing reliance on external sources of wisdom and the development of a more consistent use of her own abilities to deal with situations that arose in her classroom, "... ultimately, there's no-one but me ... I have to decide ...I'm the one who has to live with, wear my decisions about how I'll cope with things".

With respect to the actual nature of her subject as distinct from the style of her teaching, this reliance on herself became more evident after the first teaching practice session. "I read all the papers now, not just the cartoons and the headlines ... searching for ideas and examples that might grab them ... issues they might respond to ... reasons for studying science." "I'm glad it's science I'm trying to sell, at least the need for its presence in the curriculum is obvious to most kids and why they're doing it ...but it's nothing like what I suffered through at school ... the funny thing is that by doing it this way, a lot of the "good teacher" things just happen as part of the teaching this way..." (June 1993).

ASSERTION 3: A change has occurred in Jane's reflective practices over the two year period of the case study.

> I'm sure once they (the lecturers) have given us some ideas on how to teach and I've brushed up on my subject matter, I'll feel more confident than I do now. Sure, I'll make mistakes, but prac school should give me time to iron out a lot of them... (July 1991).
>
> Where is that academic formula for success when I need it? (May 1992).

That earlier apparently unshakeable confidence took quite a battering at practice school. Jane encountered so many unexpected situations when "all I thought I had to do was know my subject matter and be interesting ... and it just didn't happen that way...I didn't even guess till then that I didn't know what interesting meant to them..." (May 1992). Her indignation and desperation were clear to see at that time, "...I feel like I have to rediscover the wheel... no-one seems able to give me the help I need" (April 1992,) and "I cannot believe how naive I was when I first came in ...I had no idea..." (May 1992). And what made it all the worse for her was that "...no-one I turned to seemed to have the solutions I needed ... my lecturers just kept answering my questions with questions" (April 1992).

But even then, "I used to go home every day and wonder just where I had gone wrong ... what I had to do to avoid the same disaster all over again" (April, 1992) indicates the essential elements of early reflective practices. At this point though, the search for solutions was still external, "... when times are tough, I tend to fall back on that authoritarian teacher approach I grew up with - then I try to stop and remember what I've been taught and what I've been told is the best way to handle the situation" (May 1992).

The second practice session yielded a whole new approach to dealing with problems. "I've always wanted to help students to learn for themselves, but I've really had to dig deep in me to work out how - I can't remember learning anything like that ... in my own education or at Uni ...so I had to figure something out for myself ..." (June 1993).

Her confidence in herself had grown, and with this came a change in how she saw her role in her classroom. "There's no-one to tell me, although lots of places, especially College, have given me starting points to work it out for myself... every little thing ... it's all got to be worked out by me to suit me and my kids ... but I find it so daunting and so time consuming ... I can only hope it gets easier" (June 1993).

ASSERTION 4: There are certain discrete events which Jane has identified as influencing her reflective practices.

At the end of her course (June 1993), Jane was asked to review much of what she had said over the two years and list those events which she believed challenged her and may have resulted in a change to her reflective practices. She identified seven events or situations which she said "... made me look at things in my classroom and how to deal with them in different ways from how I would have if I hadn't had exposure to these ideas". Her list is as follows:

* Lecture on Jerome Bruner's learning theory
* Class seminars on misconceptions/alternative frameworks
* Ken Tobin's article "Social constructivist perspectives on the reform of science education"
* Reviewing the Qld Junior Science Syllabus
* Examining the Quad model of science education
* Prac school, especially the first one and especially the "year nines from hell".

Broadly speaking, these events or situations could be classified into two categories. The first of these categories would include all of the new ideas and theories which "... I had no idea existed ...when I came in to the course I thought that teaching would involve telling them everything in an interesting way ... a bit like pouring it in, I guess..". In particular, Bruner's learning theory had an impact because "... for the first time I realised that learning wasn't straightforward... that there were choices to be made about how students might learn ... even about what learning was...".

This was further complicated with her exposure to the article by Ken Tobin, "...suddenly I realised that not all teachers now think about teaching and learning theory the same way ... or that they thought the same in the past ... I begin now to understand why there is so much debate about the "right way" to do it all ... why having a Syllabus is necessary ... what comparability means ... or doesn't mean...".

The whole issue of what comprises science education became equally confusing for her, "... I used to think I just had to be interesting ... but it wasn't till prac school that I realised that what was interesting to me because it was inherently interesting wasn't to them ... I had to question what interesting really meant. Then the Quad model (a model relating to various curriculum emphases developed in the course) came along and I had a glimmer of where I was stumbling around and how I might organise what I was trying to do ... even find some common ground for me and them...".

The second category of events focussed around the "real-life" of practice school. The less challenging classes that Jane encountered provided her with little concern. They accepted her efforts uncomplainingly and seemed to provide her with little stimulus or challenge in terms of her growth and development as a reflective teacher. "I guess I was pretty complacent and naive, I now realise, that first week. I just thought all my ideas about teaching were coming together beautifully. How wrong I was...".

She mentioned the year nines in particular, along with some other isolated incidents in her classes as causing her to review her practices, her approaches to teaching and her philosophies of science and science education.

> I dreaded them ... and yet they fascinated me ... like salt and vinegar chips, you know ... you hate them but you keep wanting more. I just couldn't let them beat me. They didn't hesitate to let me know I was boring and I turned them off ... it took so long to find a chink ... to catch them off guard and reel them in ....

She thought she expended more effort with this group than with the other three classes put together.

> I pestered everyone who had them ... I even sat in on other subjects and other teachers that had them to see how they reached them ... and though I got some ideas, I didn't get answers ... I had to plough on myself and my supervisor didn't seem to care. But I got them ... sometimes when I got hold of stuff that they could relate to ... sometimes surprising stuff I just picked up from a passing comment ...not the stereotypes of motorbikes and sex ... but unexpected things like ... rusting, growing things, recycling paper. But what a lot of work ... I had to be on my toes with them all the time making sure I wasn't losing their interest ... staying alert and listening....

ASSERTION 5: There are identifiable facilitators and barriers to the process of developing more complex levels of reflective practices.

Jane, when interviewed at the end of her course (June 1993) was also asked to list what she considered to be the facilitators and the barriers to the development of her reflective practices. This section is of particular interest to those of us involved with the planning of this post-graduate course as it gives some insight into how students view the effectiveness of various aspects of the course.

Barriers:

- "my own, barely recognised preconceptions and precognitions"
- "the feeling of isolation that being part-time brings"
- "the apathy that most of my supervising teachers showed to my struggles"
- "lack of structure in the course to give us review and discussion time about problems — like a debriefing — everyone was too busy"
- "lack of confidence in my own judgements"
- "a fear of the unknown — and the consequences — and a lack of feedback"

Facilitators:

- "exposure to all the new ideas, especially when we were in classes that let us talk and interact"
- "watching good teachers and knowing what to look for"
- "some of the awful days at prac school when none of my teachers could help me"
- "time over the two years to think about it all before I had to jump back in again"
- "much as I hate to admit it, because it frustrated me like crazy, but the lack of answers from my lecturers - but at least I felt like it was deliberate, not apathetic like at school"
- "the response of the kids when I got it right - they gave me the feedback and the confidence that I could handle it on my own, in my own way..."

IN SUMMARY: SOME THOUGHTS

Jane's reflective practices did appear to change over the two year course as she gained confidence, classroom experience and encountered success with her approaches. This change in her practice was congruent with an explicit shift in the nature of knowledge she considered to be important, the source of such knowledge and how she used that knowledge. As time progressed she seemed to be relying more and more heavily on synthesising her own solutions from her past experiences and her continually growing body of acquired knowledge; knowledge acquired externally and reshaped internally as she processed ongoing experiences.

A few further thoughts with respect to course design are perhaps worth noting here. The nature of the two year part-time course seems to force students back on their own resources more than does the full-time alternative. The time factor itself also seems to give students more time to reflect and reconsider their options. Some of this time could be used more constructively, perhaps, if strategies such as journals and debriefing exercises were structured into the course and applied consistently throughout the two year period. A closer integration between the various subjects could be of benefit also by allowing for some continuity of ideas development.

One area worth exploring in the preparation of student teachers is the effect that the type of class they are exposed to at practice school has on their developing reflective practice. While no one would wish to hand an inexperienced teacher a series of impossible classes, it may be that it is only by regular exposure to more challenging situations that a student teacher is able to explore the sequence of increasingly complex reflective processes. As Jane indicated, "... I had to do something ... and fast ... because they would be there waiting for me the next day ... it had to be worked out by me to suit me and my kids...".

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SCI-TEC: EVALUATING A NON-DEFICIT MODEL OF IN-SERVICE

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ABSTRACT

The Sci-Tec project was based on an interactive, non-deficit model of in-service in which the fundamental principle was to value the expertise of all participants, and to encourage them to share that expertise with others. As part of the unfolding of the project, the participants also identified various areas of need as they arose, and these too became elements of the in-service agenda. The model has proved to be robust when applied in a wide range of schools, and with teachers who originally expressed widely varying degrees of confidence and interest in teaching primary science and technology.

BACKGROUND

In Phase 1 of the project, Focus Teachers participated in three complete weeks of in-service based on this non-deficit interactive model and then provided similar in-service to the Year 5-7 teachers in their own schools. In Phases 2 and 3, this in-service continued while they worked with two key teachers from each of three to five neighbouring schools, who were in turn providing in-service for the Year 5-7 teachers in their schools. The model was designed to avoid the dilution factor of the various 'top down' models of in-service education, in that the starting point for all programs was valuing and sharing the expertise of each group of teachers. By encouraging all participants to identify their strengths and their areas of need, it sought to ensure that the expertise being shared was what the participants themselves valued, rather than what someone else thought they ought to need. (Fensham 1991).

Progress reports on Phase 1 (Napper, Crawford & Zeegers, 1991) and Phase 2 (Napper & Crawford, 1990) of the project described in some detail its theoretical underpinnings and the procedures followed. In their evaluation sections these reports acknowledged the limitations of using the traditional evaluation procedures of trying to match outcomes with objectives particularly in a project in which many of the original objectives changed as the needs of participants changed. Nonetheless, the evaluations of Phase 1 clearly indicated to the funding body (SA Education Department) that the objectives of the project were being met and that the participants felt considerable satisfaction about the outcomes of their efforts, particularly in terms of their students' (and their own) responses to the science and technology programs occurring in their classrooms. These evaluations, particularly those conducted by Dr Mike King (An evaluation of Phase 1 of the Sci-Tec project, unpublished) and the Education Review Unit, (1991), also enabled us to direct later evaluations towards aspects of the project which were more/less effective in the eyes of the various participants, rather that always seeking some largely mythical 'overall picture'.

INTRODUCTION

Throughout the project, focus teachers have been seen, and have seen themselves as curriculum developers, planners, implementers, evaluators and initiators. That is, they have been the decision makers, not only in that they made the decisions, but also in that they determined what decisions needed to be made. They have also seen themselves, the Phase 2 and 3 teachers and the students in their classes as co-researchers in the project. In these respects the project has followed an action research spiral in which an important function of the Area meetings and the project conferences was to share ideas and generate theories to guide the participants' on-going conceptualisation, implementation and evaluation of the project.

Any kind of summative evaluation seems inappropriate in this context, particularly as the project was designed to be on-going and self-sustaining. However Focus Teachers believed it was important to record the outcomes of the project at the end of Phases 2 and 3 as these were seen to be significant points of reflection in the project's development. The key research questions chosen were:

1. What are the outcomes for Sci-Tec schools in terms of improving learning and teaching in primary science and technology?
2. What are the outcomes of this process for the participants in terms of their personal and professional empowerment?

Accordingly it was these questions which guided the evaluation process during Phases 2 and 3 which is reported in this paper.

PHASE 2

Method - Focus Teachers In Phase 2 the Focus Teachers perceptions of the outcomes were collected via:

- group discussions at Area meetings in which samples of students' work, photographs of class activities, teachers' science programs and discussions with Phase 2 teachers and principals, were used to inform and focus the discussion.
- written reports about the progress and problems in Phase 2 schools
- a formal interview with one or other of the present authors in which the Focus Teachers discussed what writing these reports meant to them, how effectively they believed it conveyed what was happening in the Project, and what specific issues arose from their report which they believed needed the attention of the project team and other Focus Teachers.

All information collected by taped interview or notes of discussions was returned to Focus Teachers to check its accuracy. It was made clear at every point that they still owned that information, and that if they did not wish any of it to be used it would immediately be deleted. This proved extremely valuable, as although minor deletions were requested only on two occasions, many excellent additions resulted from this referring back process.

As their role was to support Phase 2 teachers who were providing school-based in-service, the Focus Teachers spent little time in Phase 2 school classrooms. The information they included about outcomes in Phase 2 schools was therefore gained primarily from what the Phase 2 teachers reported during group meetings.

Focus Teachers' Perceptions The Focus Teachers reported in Focus School groups, and so 24 reports were compiled. All of the Focus Teachers reported that the Phase 2 teachers with whom they were working had significantly changed both their classroom practice in science and their attitudes towards science. How significantly these had changed however, varied considerably. From their journal records, Focus Teachers were able to produce specific examples of changes in practice and attitude experienced by at least two-thirds of the Phase 2 teachers with whom they were working. These included:

- teaching more science and technology (23)
- using strategies shared in training sessions (18)
- providing activities to which students are responding enthusiastically (16)

- moving to an investigations-based approach (13)
- moving away from 'one-off' science lessons (10)
- developing strategies to encourage greater participation by girls (8)

Changes in the attitudes of Phase 2 teachers included:

- greater confidence and enthusiasm in teaching science (19)
- greater confidence in sharing ideas and practices with other teachers (17)
- better able to identify their own needs (17)
- better able to identify their own strengths (14).

Changes occurring in Phase 2 schools included:

- more equipment/materials collected, purchased, organised and used (21)
- special events such as Science in Schools Week, Science Days and working displays of science activities (18)
- in-service programs in progress for all Years 5-7 teachers (17)
- writing or review of the school science policy (15)
- increased involvement of parents in science activities either in the classroom or at home via reports and newsletters. (11)

Method - Phase 2 teachers and principals A vital part of the evaluation of Phase 2 was to ask teachers and principals from these schools to complete an open-ended questionnaire stating the major outcomes of their participation in the project under three headings, namely:

- for you, as a Phase 2 teacher (Phase 2 teachers)
- for your school (Phase 2 teachers and principals)
- for students who have been involved (Phase 2 teachers)

They were also asked to provide evidence which would support these views. This information was coded and summaries returned to the Phase 2 participants. With their approval it was also made available to the Focus Teachers who had guided their in-service training, thus giving Focus Teachers the opportunity to appraise their own perceptions against those of the Phase 2 teachers with whom they had been working. Focus Teachers and Phase 2 teachers both believed this was valuable.

Responses were received from 36 principals (42%), and 61 (60%) of the Phase 2 teachers many of whom completed the survey jointly. These joint responses were treated as a single response.

Phase 2 teachers perceptions (N = 61): outcomes for teachers The dominant responses were that they felt more confident about teaching science and technology (36), that they gained more satisfaction from teaching science (33), and that they had gained new insights into the roles of science and technology in the primary classroom (31). There is no mistaking the enthusiasm of the statement: "I am confidently using glue guns, planning electrical activities, have introduced a Tinkering Table, and have chosen and purchased new equipment and curriculum resources for the school." [This and all quotations from teachers in this paper are taken from unpublished Sci-Tec Reports of Phase 1, Phase 2 and Phase 3 prepared by the authors for the SA Education Department.]

An appreciation of the value of a 'problem solving approach' (34), was deemed to be the main outcome in regard to the teachers' classroom practice. This change in approach was linked to the activities and references to resources provided by Focus Teachers (23), while another eleven reported gaining, and using successfully, classroom techniques such as concept mapping, assessment strategies and tinkering tables. They felt that they had gained from sharing ideas with other Phase 2 teachers (30), from the additional support provided by parents (22), from having the responsibility of ordering, gathering, storing and monitoring science resources (20), and from developing in-service skills (11).

Outcomes for the school (Phase 2 teachers and principals) Every response (N = 97) made some reference to science and technology having a higher profile, or being seen as more important or some similar phrase. The evidence for this ranged from school closure days and staff meeting devoted to science and technology to presentations of students' work in assemblies, the allocation of a science room or a science budget. Many respondents referred to all of these. Most responses included some reference to an improved resource situation (68), with the purchase or collection of new resources (44), reorganisation of resources (34) and increased use of resources (23), figuring prominently. The introduction of, or increase to, a science budget (17) was also noted.

The dominant outcome regarding changes to the school curriculum was that more and different science was being taught (40), with specific reference being made to environmental/outdoor science (13), integration with other curriculum areas (12), a student centred approach being used (11), physical science topics included (10) and visits to educational resource areas being undertaken (10).

Some or all of these outcomes were often seen also to be indicators of another outcome, namely the Phase 2 teachers' belief that there was an increase in the confidence of their colleagues in teaching science (34). Fifteen of the respondents who expressed this belief, linked it with a growth in these teachers 'knowledge about science', but it was not always clear whether they meant that this growth was in specific knowledge about scientific facts and principles, or whether it included the methods of scientific discovery, or even in some instances knowledge about teaching science. Other respondents (11) who had not mentioned an increase in 'confidence' among the other teachers, also expressed the belief that their knowledge about science had increased.

Some of the outcomes for the school were less tangible but were seen to be of great significance. Enhancement of the school's training and development program (24) and a review of the school's science policy and three year plan (24) were mentioned. Clearly, these tied in very closely with the 'higher profile' for science and technology mentioned previously as did new or enhanced participation in science-based events (28). These events included displays of the results of students' investigations in the school or elsewhere in the community (17), Australian Science in Schools Week (12) and the Hills Science Fair (7). The higher profile was not restricted to staff and students as 21 of the 22 Phase 2 teachers who had stated that increased parental support was evident also noted an increased parental awareness of the importance of science and technology curriculum.

Outcomes for students The comments from the Phase 2 teachers (N = 61) regarding what they believed the students in their classes and other classes in the school had gained from Sci-Tec were far more specific, personal and enthusiastic than those reflecting on other outcomes e.g. "Both girls and boys are keen to tackle science tasks, never asking 'what do I have to do?' or claiming 'I can't do it'. This willingness to discover for themselves is just wonderful." It was also clear that teachers were better able to produce supporting evidence regarding these outcomes. For example, 41 of the 61 reports make reference to the students' enjoyment, interest or enthusiasm when participating in science and technology activities. This claim was supported by observations that, they ask for more science and technology lessons (21), they participate in these activities outside class time (20), they are keen to participate in the special events (18), and that the girls participate far more eagerly than they had done previously (12). Similarly supported were outcomes involving the development in the students' problem solving skills (34) and group skills (19), and the view that the class as a whole had developed a more co-operative approach to learning (11).

The claim that students began to accept greater responsibility for their own learning (17) was supported by observations that they initiated their own activities based on toys or animals brought from home (11), were more willing to take risks (10), looked for new solutions to the problems (10), and became more confident in tackling new or different tasks (9).

PHASE 3

The methods of data collection and analysis used in Phase 2 were repeated in Phase 3 with minor variations.

Focus Teachers' Perceptions Focus Teachers reported that Phase 3 was a significant point in the development of the project, because they now had greater familiarity with the type of program they would be running, had broadened their knowledge of resources (which included people, places and materials), had developed a range of in-service skills and strategies to use in Phase 3 and had had the opportunity to reflect on and evaluate the workshop programs of Phase 2. They also believed that they had developed more confidence in their interactions with peers and principals.

Although certain aspects of Phase 3 were changed because of this learning experience, and the fact that the needs of the Phase 3 teachers were different from those of the Phase 2 teachers, the essence of the model was retained. There was a strong emphasis on a meeting format which included an activity session, a sharing time and a planning time, there was still an emphasis on the development of networks which operated between the meeting times, and there was still a commitment to a program based on participant decision making.

Phase 3 teachers: data collection In Phase 3, 38% of principals (N = 40) and 58% of teachers (N = 53) responded. Joint responses from the Phase 3 teachers were again treated as a single response. They gave a wider range of responses than occurred in Phase 2, but patterns could still be discerned.

The Phase 3 Teachers' views: outcomes for teachers (N=53) The Phase 3 teachers clearly conveyed that they were motivated and enthused by the in-service program (31) using terms such as supportive (8), valuable (7), practical (6), informative (5), relaxed (3), challenging (2), stimulating (2). The importance of the sharing sessions during the meetings (13), the establishment of networks across schools in the district and within their own schools (9) were also seen as important features. Eight responses indicated that the teachers were keen to have follow up sessions once Phase 3 had officially finished and eleven indicated that the teachers believed the project should continue into Phase 4.

The Phase 3 teachers referred to their changed attitudes towards teaching science, referring specifically to increased confidence (26), enthusiasm (5), interest (4) and enjoyment (3). In terms of their teaching skills, every response cited at least one example of professional development including increased awareness of the resources available (21), the value of networking (19), the development of skills to in-service other teachers (18), an increased awareness of the teaching methods involved (14), gaining of ideas for teaching science (9), increased science knowledge (9) and reinforcement of their beliefs about how children learn best (9).

Outcomes for students (N = 53) Twenty one Phase 3 teachers stated that their students displayed a greater interest, excitement and enthusiasm for science. Evidence which supported their views included an increased use of equipment, students requesting science, students bringing things from home and the development of scientific vocabulary. Other outcomes included the students being actively involved in investigations (20), improved skills in areas such as recording and researching (13), better skills in problem solving (8), the development of new science concepts (7), and increased confidence (4).

Outcomes for the Phase 3 schools (Teachers and principals) (N = 93) Sixteen of the Phase 3 schools appointed key teachers in science/technology or science and technology. Although only six teachers specifically indicated that science had taken on a higher profile in the school, 154 comments gave evidence which indicated that this was the case. Examples included the purchase and reorganisation of resources (39), participation in ASISW and other science related events (26), teachers meeting regularly to plan science activities (20), different science being taught more often (19), an increase in community awareness via special science days/evenings or displays in the community (15), an increase in the budget allocation (10), and school science display areas established (7). A sample comment: "The main outcome is that we now give science and technology a go. Instead of floundering around wondering where to begin, we now flounder around having an exciting time and knowing where to get ideas, information and resources."

WHAT ABOUT ME? PERSONAL OUTCOMES MOST VALUED BY FOCUS TEACHERS

The unwavering enthusiasm of the Focus Teachers sustained through three and a half years was perhaps the most outstanding feature of this project. Why did they do it? In an attempt to find out, we asked them to come to the final focus teacher conference armed with their personal journals, and prepared to write about what they thought they had been enabled to do by their participation in Sci-Tec. What they wrote provided such a rich compendium of evaluative data that selection rather than summary is clearly the appropriate way to present it, although the comments can be grouped under six headings.

Personal gains The comments from Focus Teachers highlighted personal gains from their participation in Sci-Tec as much as they did professional gains. Increased confidence, knowledge, teaching skills and higher status in the school have ranked very highly, but underlying these comments there has been a perception which is difficult to make explicit but nonetheless important to record. Perhaps this comment gets close to it: "The children have become independent yet cooperative, prepared to take risks in their commitment to learning. Even more importantly, I have too, and not just in science."

Confidence and Self-Esteem If we accept the view that self-esteem is based on what we believe others think of us, then there is no doubt that the self-esteem of many focus teachers has changed dramatically. One teacher commented: "The other teachers tell me that they feel that there is plenty of support available which gives them confidence to try activity-based investigations. They actually enjoy talking to each other, sharing successes and laughing about failures as they look at trying another way. This has given me a new lease of life, a new direction, a new interest, a new challenge." Another realised "how other teachers were in need of supportive, exciting professional development, and that they had lots to share too."

Skills Development When they were asked to consider whether participation in the project had led to any changes in their ways of doing things, most of the Focus Teachers responded along the lines of "Not only that, but I am doing different things." When this response was followed up later, a flood of 'new skills' appeared in the responses. The range of skills was very impressive, and there was a remarkable consistency in terms of what could be termed core skills. These included:

- planning and programming
- improved time management
- resources management (purchasing, budgeting, monitoring, storage)
- organising events (school, District, Area levels)
- writing (newsletters, staff news, submissions)
- policy development (not only in science)
- evaluation methods (effectiveness of workshops, programs)
- decision making
- interpersonal skills (creating group cohesion)
- running staff meetings, parent workshops, Phase 2 and 3 workshops, school closure days.
- public relations skills (media, parents, Area)

The skill which many seemed to be most pleased about was the skill of enabling other teachers to solve classroom problems, in particular the problems of fitting science and technology into an already crowded curriculum, and that of involving their students in their learning.

> The teachers were thrilled at the way their classes had taken to science when they used the Sci-Tec approach, but found that it sometimes conflicted with other areas and also took a lot of class time because the children were so interested. Gradually we learned together that we could use these methods in many other learning disciplines and that we could assess their skills and knowledge development in many areas simultaneously. We didn't solve the problem, it just went away.

Status Many people commented that they now believed parents, the principal and other teachers treated them differently. Most linked this to their new skills, responsibilities, achievements and prominence within the school and beyond, but others also claimed that it was at least in part due to external factors such as Departmental backing for the project and parents wanting more science and technology for their children e.g. "The bush telegraph spread the word. I was invited by 'home teachers' (ie mums) to spend the day on stations. Before Sci-Tec they didn't know I existed, but like so many parents, they are now pillars of support."

There is no doubt that the Department-wide support for the project, especially via payment of relieving teachers was seen by most teachers as the crucial element in their skill development, enhanced status and ultimately the success of the project. The sincerity with which the Focus Teachers wrote of their appreciation for this support, indicated the importance which they attached to it. This response is typical:

> When the project began I was starved of professional development, and was a pretty tired teacher. I'd tried a few things in isolation but they were only semi-effective. Suddenly (and I do mean very suddenly) I realised that things I had longed to do in my class were educationally highly regarded. The energy released by the 'big bang' of the first Sci-Tec gathering produced an inner change. I felt valued as a resource person because both the Department and the Area (0.2 release time) allocated time for me to put into practice these ideas bubbling up inside. I had brushed up my adult learning knowledge, and I had a practical/interesting barrow to push. Since then I have become a self-trained, self-motivated, self-confident Sci-Tec facilitator. People look forward to meetings I run, they share their knowledge and skills, and they welcome me into their schools. I no longer feel I am 'just a classroom teacher' in a sea of others, I have a valuable network of colleagues through Phase 2 and 3 throughout city and country.

Working with adults It is clear that Sci-Tec provided opportunities for teachers to interact with adults in ways other than they had done previously. Reports of these interactions which occurred both within and beyond the school community, are often preceded by statements such as "I knew that I communicated well with children, but I felt that I was, 'just a teacher' when interacting with other adults." There are many reports of teachers using with adults the listening, questioning, student enhancement and management skills which they had developed in classrooms. Conversely, using adult learning principles in their classrooms, was also a great success.

> My dealings with parents have changed radically. The fact that I am learning along with the teachers I am in-servicing has made me much more tolerant of what and how quickly other adults learn. I now give clearer directions, explain my thinking, listen to responses, ask parents what they want to do, accept a variety of views, and make far more use of their expert knowledge. My improved assertiveness assures that this all contributes to (rather than shatters!) the learning environment in my classroom.

Further career opportunities An essential ingredient in the success of Sci-Tec was the stable school staff establishments. Where staff changes occurred, it often took a great deal of the Project Coordinator's time to re-negotiate an efficient structure. Key teacher appointments sometimes created problems with role definition, but over-riding all this were the career opportunities the project offered. Promotions to principal, deputy, key teacher (in areas other than science as well as in science), coordinator and project officer were won by various Focus Teachers. Some of these promotions helped the project, others did not, but there is no doubt that those who were promoted felt that participation in Sci-Tec had contributed to their success.

> The experience I had in running training and development, and the resources I collected led me to value myself more. I won a key teacher job in Health Education in 1990, and a Coordinator position 1992-3 in planning and design skills. I feel that my involvement in Sci-Tec was a prime factor in building the knowledge, skills and experience necessary to win these positions.
>
> A Phase 3 principal gave me a stunning reference about my effect on the school to put in my "I am wonderful" file to present at my Coordinator interview. Then the principal of my school appeared and thanked me on behalf of all the Phase 2 and 3 principals, and broke out the champagne. The Phase 2 and 3 teachers presented me with flowers and a wonderful certificate of appreciation. As you know, I got the Coordinator job.

FINDINGS

> I found the project a great boost to my morale and confidence. This came from being with the same supportive group of people over a period of time where we worked and learned together and shared the problems and joys we experienced.

Sharing expertise There is no doubt that the vast majority of Sci-Tec teachers felt they developed their expertise and confidence in teaching science. This is not to say however that each now feels fully confident or indeed expert in the area. For some it means that they now teach science regularly, for some it means that they are able to assist others with their technology programs and for some the methodology has become an integral part of their teaching practice across the curriculum. The responses of Phase 2 and 3 teachers indicate an incredibly broad range of outcomes related to professional and personal development. In most projects this would be passed off as an unfortunate consequence of participants entering the project with a divergence of skills, abilities and interests. In Sci-Tec it is celebrated as an indicator of having achieved the aim of each participant valuing the skills and knowledge (s)he already has, and sharing these personal, idiosyncratically developed skills with others.

Skill development Focus Teachers and Phase 2 and 3 teachers all reported an impressive growth in skills not only personally but in the teachers with whom they worked. The outstanding features of this were the clear, specific identification of these skills, and the many examples given which showed that they were applying these skills outside the classroom. These factors may be directly attributed to the emphasis placed on teachers identifying and developing the skills which they believed they most needed in order to teach science and technology more effectively. They knew what they were after, and they got it.

Shared ownership Even in the first week of Sci-Tec, all participants were expected to take part in 'setting the agenda'. Over 95% of inservice time (and money) was spent in schools, with each school taking its turn to host the workshop and to co-ordinate the agenda items sent in from the others schools. These meetings were held regularly and scheduled well in advance. A consistent threefold structure was soon found to be most effective, and was used thereafter. Each workshop meeting consisted of:

- sharing information, resources, ideas etc
- a display of some things that had gone well (or badly)
- trying something new that teachers had requested.

A review of participants' comments shows how closely teachers identified with the idea that they were constructing the project rather than having it imposed on them. Focus Teachers also reported that the fact that we returned to them all data we collected, and that we gave them the unquestioned right of veto regarding the use and interpretation of the data, enhanced their sense of shared ownership of the project.

Support Focus Teachers and Phase 2 and 3 teachers and principals all reported that outcomes were directly linked to the support they received. Support from the Education Department, their principal and the project team were essential, but vital support was also received from Focus Teachers, Area Officers, colleagues, Phase 2 and 3 principals and teachers. It was frequently acknowledged that the greater the number of 'levels' offering support the better everything seemed to go.

Of particular importance was the close support of a colleague acting as co-worker, confidant and critical friend. The notion of having two Focus, Phase 2 and Phase 3 teachers in their respective schools was particularly commended. Of similar importance was the insistence that at least one of the two teachers must be a woman. Many teachers reported that reflecting the gender balance in Years 5-7 classes immediately helped dispel the myth that only men can provide expertise in science and technology. The fact that the project co-ordinator was a woman helped too!

Participants have recorded the growth of support networks within and between schools. Sharing ideas and resources, reciprocal classroom visits, planning and teaching in teams (often using cross-age and peer group tutoring), volunteering successful strategies, and science/technology activity sessions in staff meetings, have revitalised many Sci-Tec schools.

Resources There was overwhelming agreement by all participants that access to resources was the key factor in improving teaching and learning in science and technology in Sci-Tec schools. They frequently commented that being aware of the range of resources (equipment, print and other media, people, venues) that were available, and knowing how to get hold of them, was a fundamental requirement for improvement.

Many teachers also reported that once students had access to basic equipment, like magnets, magnifying glasses, aquaria, batteries and bulbs, thermometers, screwdrivers and pliers, and were encouraged to 'use up' consumable materials like paper, straws, pop sticks, masking tape, nails and string, they became far more involved in the investigations they were conducting. Teachers particularly valued the collaborative and independent learning skills they saw developing in their classes, and noted the changes which this had brought about in their teaching methods. One teacher reported: "I now understand what you mean by an interactive approach to teaching". Another said "the girls in my class think that if this is what science is about, they'll be in it".

CONCLUSION

The Focus Teachers were asked to respond to the draft report of this evaluation as part of its validation. They agreed unanimously that it encapsulated their reflections on the outcomes. They also valued the opportunity to share other participants' reflections.

Confidence and empowerment build slowly. It takes time to establish trust between participants, for them to feel comfortable with sharing personal insights, suggesting new ideas, questioning traditional practices and values, and supporting each other in a sense of shared ownership of the tasks and the outcomes. This personal empowerment leaps out from the Focus Teachers' statements about the personal and professional outcomes for them. But there is more, for they also see themselves as empowering agents.

> I now understand what depth and breadth of expertise in teaching science and technology exists in every teacher and therefore in every school. I also understand that I can help them to recognise, develop, value and share that expertise.

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STUDENT UNDERSTANDINGS OF NATURAL SELECTION

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ABSTRACT

This paper examines the continuation of a study investigating senior secondary students' understanding of concepts in biology. In this study, year 11 student understandings of natural selection were examined by questionnaire using different question formats. The SOLO taxonomy of Biggs and Collis (1982) was used as the theoretical framework with which the quality of student learning was assessed.

This paper puts forward the usefulness of the SOLO taxonomy in assessing student understanding in biology in general and in examining student understanding of the concept of natural selection in particular. The paper goes on to examine the implications of these results and raises issues which have applicability to criterion-based assessment in secondary science.

INTRODUCTION

Natural selection is an important concept in biology curricula. The possession of the scientifically valid conception of the mechanism of natural selection and its role in the characteristics exhibited by populations over time relies on the understanding and integration of at least two subordinate processes. Students must realise that new characteristics or traits arise through random changes in the genetic material of individuals in the population. Secondly, they must understand that these traits will survive or increase in frequency in the population or decrease in frequency and possibly disappear because of individuals' reproductive success under the particular environmental conditions in which that population lives.

Student understandings of the mechanism of natural selection have been investigated in studies of student groups from 7th grade to university undergraduates (Brumby, 1984; Bishop & Anderson, 1986; Lawson & Thompson, 1988). These studies have been designed to reveal misconceptions held by the student groups under study. Research has shown that students often have misconceptions or naive alternative conceptual frameworks about natural phenomena, and the concept of natural selection is no exception in this regard.

The author is presently conducting a study of the use of the SOLO (Structure of the Observed Learning Outcome) taxonomy of Biggs and Collis (1982) to examine students' understandings of some concepts basic to the study of senior secondary biology. Because the SOLO Taxonomy has been proposed as a logical means of breaking down the general aims of science education into specific classroom aims and activities and for providing a reliable means of criterion based assessment (Collis & Biggs, 1989; Pallett & Rataj, 1992), it is important to examine the taxonomy thoroughly in relation to science concepts. This paper presents results of the latest part of this study. This is an examination of Year 11 students' understanding of the mechanism of natural selection. The purpose of the study was to extend results of the previous study (Creedy, 1992) into the senior secondary years and examine the structure of these students' responses.

The SOLO Taxonomy

Learner responses can be classified objectively and systematically according to their structural organisation using the SOLO taxonomy. This structure of response is a clue to the quality of learning, a discrimination between well learned and poorly learned material, producing a non-quantitative way of assessment that is as objective as possible. Though the model builds upon Piaget's stages of development and "assumes a latent hierarchical and cumulative cognitive dimension" (Romberg, Jurdak, Collis & Buchanan, 1982), it is fundamentally different. The model proposes that within at least five modes of functioning, response structure shows a cyclical pattern of five levels: Prestructural, Unistructural, Multistructural, Relational and Extended Abstract (Watson & Mulligan, 1990). Each level builds on or subsumes the previous level.

The model makes a number of assumptions. A student's responses should be able to be classified into one of the levels. In any given topic area, a student will move progressively through these levels exhibiting the characteristic responses of each level, and will progress through the levels at a rate which reflects his/her growing experience, comprehension and maturity in the subject. That is, success at one level will usually be preceded by success at all the lower levels.

THE STUDY

This investigation was carried out by examining 20 Year 11 biology students. In the class there were 12 girls and 8 boys. These students had recently completed a biology unit which included the concept of natural selection. The students were given written questions and asked to answer them in as complete a manner as was possible. Students were not given guidance as to the structure of response required other than the instruction to give their 'best' answers. Three questions were used. Questions 1 and 3 were 'open' format questions, standard essay question format in which students were asked to supply as much information as possible. Question 2 was a superitem or 'closed' format question designed according to the SOLO superitem format (Romberg et al., 1982; Cureton, 1965; Collis & Davey, 1986; Wilson, 1989). Questions 2 and 3 had been used in a previous study examining student understanding of three different biological concepts (Creedy, 1992). The results of this previous study indicated that the quality of student answers was dependant to some extent on the type of question asked. As a result, both types of question were included in this study.

Question 1:
How would you explain biological 'natural selection' to someone? This person has no knowledge of natural selection, so your explanation must be as complete as you can make it.

Question 2:
Rabbits were introduced to Australia in Western Victoria in 1859 when Thomas Austin released a consignment of rabbits on his property, Barwon Park Estate. He had bought the rabbits for hunting purposes. After 3 years the rabbits had increased so much they became pests. Austin's rabbits escaped his property and spread alarmingly when part of the fence surrounding the property was destroyed during a bushfire. Because of this and other releases of rabbits, within 25 years from the time they were introduced, rabbits had spread over 3/4 of Australia and were causing damage to grazing land.

Rabbits cause extensive damage to areas because they eat roots of plants in dry seasons making it impossible for plants to regenerate and because they dig burrows. Many methods of control were tried, but none had much impact on rabbit numbers. In good conditions, it

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takes only 3 years for one pair of rabbits to multiply to 13 million. Biological control was tried in 1950. A few rabbits were injected with the myxoma virus (from South America) and then released. This virus, deadly to rabbits, is spread by fleas and mosquitoes from live rabbits, not from dead ones. By 1955, 90% of the rabbit population had died. In recent years, however, two new developments have been noticed:

1 The rabbit population is increasing even though the virus is widespread.

2 The virus seems to be becoming less deadly, with 40% of infected rabbits commonly surviving as opposed to the 1% survival rate observed when the rabbits were first released.

A. [Unistructural] Why were rabbits introduced to Australia?
B. [Multistructural] How many years were there between the time rabbits were introduced and a method of biological control was tried?
C. [Relational] What change, if any, would you expect to see in rabbit numbers in the future? Give as much information as you can.
D. [Extended Abstract] Develop a general theory which would explain developments (1) and (2). (Explain why you think (1) and (2) are happening.)

Question 3:
'A mixed population, containing some dark brown and some white mice, lived in a granary (grain storage depot). There was very little light in the building and the mice were causing so much damage that cats were introduced as a control measure. After many generations, the mouse population was much smaller and all the mice were dark brown.'

Explain, providing as much detail as possible, why these changes in the mouse population occurred.

Criteria for superitem format

The questions in the closed format are structured to relate to the unistructural, multistructural, relational, extended abstract hierarchy by using criteria which fit the following summary specifications:

- unistructural (U): The question is designed to show that the respondent has sufficient grasp of the material to *select* the correct response from the information given.
- multistructural (M): the question would require the respondent to perform two or more separate operations in sequence on the information available. Each operation required should be seen as a closure and the process is often analogous to following a recipe.
- relational (R): the question would be designed to require the respondent to find an underlying principle or relationship which enables integration of the relevant information contained in the stem.
- extended abstract (EA): the question should require the respondent, either implicitly or explicitly, to go outside the given information to formulate an hypothesis or call up abstract conceptualisations and possible relationships that are then tested against, or used with, the information in the stem to formulate a comprehensive response.

Scoring

The students' responses were judged on correctness and 'fit' into one of the SOLO levels. The type of misconceptions were also noted but will not be dealt with in this paper. Answers to superitem questions and to open format questions were scored according to their structure:

they were assigned to SOLO levels according to the criteria outlined above. Student responses to open format questions (1 and 3) and superitem question D (which is an open format question itself) are summarised in Table 1.

Question 1: Explain biological natural selection. Open-format.
There were three questions which were classified as 'Prestructural', or unable to be coded, either because the student did not answer the question or because the answer given was characterised by denial, tautology (not rote learning but simple restatement of the question) and transduction (a stab in the dark based on guess, emotion or perception) (Biggs & Collis 1982):

> Natural selection is when animals or organism reproduce without having any human or any other animal interaction with these organism. So (animals) >organism pick themself [sic] who they want to reproduce with this is called natural selection."

There was one typically 'Unistructural' answer. This structure occurs when the subject relates one piece of relevant information to a conclusion. The student closes rapidly on a categorical judgment (Biggs & Collis 1982):

> I would say that natural selection means...the population may alter to adapt to the environment.

Most students' answers were typical of the 'Multistructural' SOLO level In this form of response, the student supplies several pieces of information all of which are relevant. The student attends to several relevant points but has failed to integrate them in order to explain what is happening, leading to piecemeal, conflicting and inconsistent judgments (Biggs & Collis 1982). Students typically responded by giving one or more examples of natural selection, relating a series of conditions and consequences in step-by-step fashion without presenting an integrated explanation:

> In natural selection there may be two types of the one species e.g. fast dogs and slow dogs. If the dogs have to catch fast animals then usually the faster dogs survive and the slower ones die. Or if there are white mice and dark mice in a shed with cats with no lights the dark ones are more likely to survive.

Two students presented 'Relational' answers. Relational structures show an integration of relevant pieces of information to give a coherent explanation and an overall concept (Biggs & Collis 1982). These students could identify a process in which environmental conditions allowed some organisms to have a reproductive advantage over other organisms:

> ...occurs when the environment seledts [sic] an advantage. The organism does not change to suit the environment but the variation is already present in some organisms...[suitable example given and explained]...In Natural Selection, those organisms with an advantage Survive & pass on their advantage to their offspring. Those organisms without and [sic] advantage will find it harder to survive & will probably die.

No answers were deemed to exemplify the 'Extended Abstract' level. This theoretically oriented response would include the integration of all relevant pieces of information from the data presented and an 'extension' of the response to integrate relevant information not presented in the stimulus such as examples and analogies. A student presenting this level of response is able to generate his/her own rules to cover all cases, including hypothetical ones, and to introduce abstract principles which are not given directly in the data, deduce from those principles that certain events may or may not follow, and test this deduction against the data (Biggs & Collis 1982).

Question: Mice in the Granary. Open-format.
One student presented a Unistructural answer, fixing attention on one physical factor, light. This particular student did not answer Question 1 and only answered parts A and B of Question 2:

> These changes in the mouse population occurred as the physical factor such as light, according to Darwin's law, things can be affected by physical factors.

Most students answered this question at the Multistructural level, again listing a number of conditions and consequences and failing to draw conclusions and generalise:

> ...The white mice were more easily seen be [sic] the cats so they become the easiest prey. The brown mice also were killed but not in the same numbers because they were camouflauged [sic] and could easily hide.

Six students presented 'Relational' answers to this question; again these students could identify a process in which environmental conditions allowed some organisms to have a reproductive advantage over other organisms. Four of these students had answered Question 1 at the Multistructural level. The students had seen this question in their unit studies (it is a modified past HSC question) and it would be expected that students should be able to provide a higher level answer:

> This is a specific example of Natural Selection with mice being prey and cats the preditors...reason behind the population being smaller and dark brown...these characteristics...had an advantage...darker mice were harder to see...less brown mice would have been killed by the cats...more white mice were killed leaving less to produce white mice s [sic] their offspring...with passing of generations this cycle would thus led to less and less numbers of white mice and a greater number of brown mice..."

> ...The environment selected that the dark brown mice had an advantage...The darker mice survived to pass on to their advantage (which was their colour) to their offspring.

> ...The dark colored mice become the dominate [sic] colour because, their dark colar [sic] was there [sic] survival characteristic and so they reproduced passing on the dark colouring and slowly taking over the white mice population as they were been [sic] eaten or killed more frequently.

No answers were scored at the Extended Abstract level.

Question 2: Myxomatosis. Closed- or Superitem-format.
All students answered Part A (Unistructural) at the Unistructural level:

> They were introduced for hunting purposes.

Part B (Multistructural) yielded mixed results. The question requires students to perform a sequence of steps concentrating on information in different parts of the stem. While all students recognised that this process was required and provided a single figure answer, 6 students were unable to arrive at the correct figure.

One student did not answer Part C (Relational), and two students provided typical Unistructural answers:

> I would expect the rabbit population to grow as the resistant rabbits keep on breeding.

Most students provided Multistructural answers to this part of Question 2

Part D (Extended Abstract) was most like an open-format question. Three students did not answer this question; their 'responses' were therefore Prestructural. There were no Unistructural answers, and only two Relational answers were recorded. Fifteen students responded with Multistructural answers, usually repeating the sequence of conditions and consequences presented in the stem.

TABLE 1
NUMBER OF STUDENT RESPONSES IN EACH SOLO CATEGORY
('OPEN' FORMAT QUESTIONS)

	SOLO Level			
Question	Prestructural	Unistructural	Multistructural	Relational
1	3	1	14	2*
3	0	1	13	6*
2D	3	0	15	2*

* The same two students produced Relational responses for each question.

Table 1 clearly demonstrates that most students have answered Questions 1, 3 and 2D using a Multistructural level of structure. No questions were scored in the Extended Abstract level.

Response Patterns in Question 2 (Superitem)

The superitem itself consists of a 'stimulus' which may include figures, tables or text (also called the 'stem') and a series of questions based on this stimulus material. Each question is linked in order to either the Unistructural (E), Multistructural (M), Relational (R) or Extended Abstract (EA) levels of the SOLO hierarchy. In this way, students were required to think about and use the given information in an increasingly more sophisticated way in order to obtain a correct result. The pattern of response will reflect the "level of concept development achieved" (Wilson, 1989). If students answer each question correctly at the level required, the response pattern of their answers should be U M R EA. Other patterns are possible. Students who have reached the limits of their knowledge or skills (or indeed motivation) in a particular topic area under these conditions, will present responses which are limited by this ability. A student may, in fact, fall back to an even lower level response structure. The response patterns of students in the study group and the numbers of students showing each response pattern appear in Table 2.

TABLE 2
STRUCTURE OF ITEM ANSWERS WITHIN THE SUPERITEM

Response Pattern	Number of Responses
QUESTION2	
UMPP*	1
UMUM	2
UMMP	2
UMMM	13
UMMR	1
UMRR	1

*P = Prestructural response

It is apparent from an examination of the response patterns in the superitem that all students can answer items to at least the Multistructural level. For all but two of these students, this is the greatest level of response reached in this superitem. Two students were able to extend their answers to the Relational level.

DISCUSSION

The results of this study demonstrated that the responses of students in this group to the questions could be classified according to their SOLO level in the concrete symbolic mode. Additionally, the results of the previous study (Creedy, 1992) were substantiated; the superitem did not appear to elicit responses of a higher SOLO level than the open-format questions.

It was disappointing that most of the group under study could not produce responses which satisfy at least the Relational level criteria, and none of the students were able to recognise more than one process involved in the questions; the idea that there must be random genetic changes taking place in individuals is ignored. The ability to deal with more than one process may represent a second 'cycle' in the concrete symbolic mode; that is a student may progress from being able to discuss the workings of one process to the ability to discuss more than one process (a superorder Multistructural level). Research into student understanding of concepts related to evaporation has suggested that there exists more than one cycle in the concrete symbolic mode (Levins, 1992). In any case, the questions asked did not elicit responses which dealt with more than one process. Only one of the questions asked students to predict an outcome based on available information. It may be that questions asking students to respond only to the question at hand may prompt lower level answers. The use of questions requiring students to predict outcomes will be the object of future study.

The SOLO Taxonomy has been proposed as a tool in curriculum development (Stanbridge 1990), for developing specific classroom aims and activities and for providing a reliable means of criterion based assessment (Collis & Biggs, 1989; Pallett & Rataj, 1992). As the use of the SOLO taxonomy requires students to respond to particular questions, it is essential that the effect of question type on student response be known.

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DEVELOPMENT OF A HYPERTEXT COMPUTER PROGRAM TO ENHANCE THE SCIENTIFIC WRITING OF UPPER SECONDARY PHYSICS STUDENTS

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ABSTRACT

This is a descriptive account of the development of a hypertext computer program to enhance the scientific writing skills of upper secondary physics students. The program facilitates the integration of concept mapping, inferential reading, student-teacher dialogue, models of writing in the scientific register and the clear display of assessment criteria. This was achieved by the design and use of a program called 'HyperCardPhysics' (HCP) for Apple-Macintosh computers. It has been tried out in a number of schools in South Australia with positive results.

INTRODUCTION

Eight computer-based modules for Year 11 physics have been developed as part of a larger project called 'Scientific Literacy Development Plan' (SLDP), using the HyperCard software package for Macintosh™ computers. Each module of 12 lessons is called HyperCardPhysics (HCP) with its topic name, for example 'HCPelectricity', and is supported by a Teacher's Manual and a lesson pack of overhead transparencies. The SLDP project is investigating the practicality and effectiveness of integrating a computer-aided technique of writing, such as the HCP, into the general teaching of the concepts in a number of topics in a senior secondary physics course.

The need for this project arose from the requirement of the Senior Secondary Assessment Board of South Australia (SSABSA) that Year 11 students demonstrate literacy skills through writing. Previous reports had indicated that there was inadequate skill in this regard (Gilding, 1988, 1989). Also, analysis of Year 12 physics examination results over the last five years has indicated poor performance in extended writing answers.

Current understanding of the writing process sees it as a socio-cultural practice and is inseparable from the discourse in which it takes place. There is no clear pedagogical method favoured for its development; Gilbert (1991) provides a critique of the various strands of research into writing as social practice. One pedagogical method is the explicit teaching of genres in various subject areas, (Rothery, 1989; Derewianka, 1990; Hardy & Klarwein, 1990; Martin, 1990). The computer-aided writing tool, HCP, described here uses the genre approach to writing.

The advocates of a genre approach to scientific writing, such as Martin (1985) and Lemke (1990) believe that a genre structure assists students in developing a language register of science. The genres of factual writing generally advocated are: recount, report, procedure, explanation, exposition and discursive argument. All of these genres of scientific writing can be used to satisfy the requirements of the Writing Based Literacy Assessment (SSABSA, 1992) in science. However the explanation genre is the major form of essay required for the Year 12 physics examination. The explanation genre requires the integration of language acquisition and concept development and represents a transition from a 'knowledge-telling' approach to a 'knowledge-transforming' as described by Bereiter and Scardamalia (1987). This implies the use of cognitive strategies such as those used in problem solving and relies on a certain amount of structuring of mental representation.

THE PROCESS OF PROGRAM DEVELOPMENT

Using HyperCard for scientific writing

Hartley (1990) describes three levels of computer-aided writing: first, word processing for deletions, substitutions and rearrangements; second, post-writing editing for spelling, grammar and writing style checks; third, interactive routines that assist throughout the composing process such as planning, organising and linking. Development of these programs, according to Hartley (1993), is in its infancy but preliminary results indicate that significant change to cognitive writing strategies occurs only at this third level of computer assistance. The HCP attempts to meet the third level requirements. The methodology of interactive routines is called a hypertext methodology in this computer application.

The hypertext methodology, the non-linear linking of units of information (Collier, 1989), is one way of providing assistance with planning, organising and linking throughout the composition process. This has been used by Neuwirth, Kaufer, Chimera, and Gillespie (1989) in an application called 'NOTES'. Another application is the program 'Writing Environment' (WE) developed by Smith, Weiss, and Ferguson (1989). The purpose of developing the HCP reported here, was to construct modules that would integrate concept mapping, reading texts, modelling of writing genres, and word processing of essays within specific physics modules.

The HyperCard software package was chosen for the following reasons: first, the Macintosh environment is well known to be user-friendly; second, it is available to all users of Macintosh machines as it comes free with every machine purchased; third, the use of Macintosh machines is increasing in secondary schools. HyperCard allows considerable choice in the creation of non-linear ways of linking of information. The routes taken by the individual users are called the navigation pathways. For ease of navigation, new 'menus' were created and existing ones such as 'file' and 'edit' were modified. Besides the hypertext navigation facilities, HyperCard also includes text creation and graphics tools which are required for concept mapping. The integration of these facilities make HyperCard a useful hypertext application for the development of modules in physics for scientific writing.

The HyperCardPhysics modules (HCP)

The eight modules developed for the Year 11 physics course in South Australia, are shown in Fig. 1. Within each module, students navigate their own pathways through concept mapping and the units of reading texts, units of writing models and the typing/editing sections.

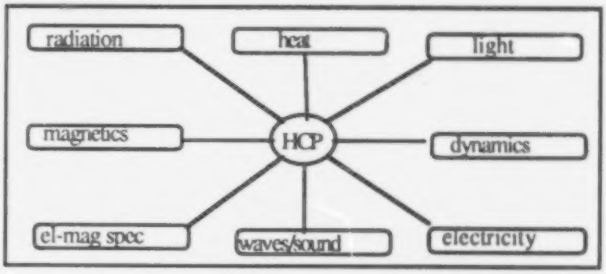
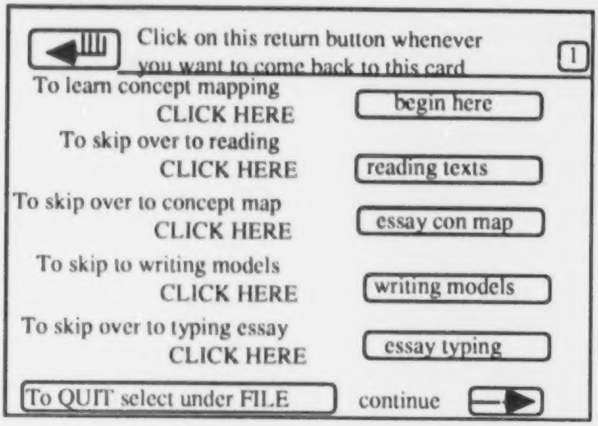


Fig. 1 HyperCardPhysics (HCP) modules

The program output for the student is the construction of a concept map, and the composition of extended prose in the form of either an explanation or exposition essay as a word processed document. The components of the HCP are designed to enable students to progress through several activities at their own pace and according to their own pathways. The choice of pathway is presented to the user as indicated in Fig. 2.



Click on this return button whenever you want to come back to this card

To learn concept mapping CLICK HERE

To skip over to reading CLICK HERE

To skip over to concept map CLICK HERE

To skip to writing models CLICK HERE

To skip over to typing essay CLICK HERE

To QUIT select under FILE

Fig. 2 Pathways to module activities

The components of a HyperCardPhysics module

HCP concept mapping A typical HCP module provides a list of concept labels as menu items which can be selected, arranged and continuously re-arranged during the construction of the essay concept map. The 'line' tool and 'erase' tool are easily accessed under a menu called 'mapping' which enables the user to make links between the concept labels and to increase the complexity of the structure with cross links to related concepts. Under the menus 'list of concepts' and 'list of relational statements', the students can make appropriate selections. Under the menus 'new concept' and 'new relational statement' they can create their own concepts and relational statements for incorporation into the concept map.

The introductory section progressively teaches the skills of creating a concept map, while the 'essay concept map' section is dedicated to the concept map for the chosen essay topic. There is provision for students to make numerous concept maps in the same module.

HCP writing models The HCP module provides a number of writing models that illustrate concept selection, genre selection and language register selection. The focus in this project is on the explanation and exposition genres of scientific writing. These two genres allow for knowledge-transforming skills(Bereiter & Scardamalia, 1987) such as clarifying meanings, discovering implications, establishing connections to prior knowledge, and finding inconsistencies, throughout the composing process. An assessment scheme for grading essays in the explanation genre was developed from the SOLO taxonomy of Biggs and Collis (1982) and is reported elsewhere (Cronin, Brown & Pollard, 1993). The assessment scheme is included with each of the writing models.

The HCP module provides definitions in a particular physics topic for the concepts listed and these definitions can be readily accessed from any part of the program. The module also provides verb phrases, sentence connectives and word analogues for scientific equations that can be assembled on the concept map as relational statements between concepts. These can be later utilised in the composition of the essay.

HCP reading texts The HCP modules provide a number of examples of journalistic and other types of articles which present current scientific applications in each of the physics topics. The use of the HyperCard software tools enables the user to select one or more of the concept terms which are then automatically transferred to the concept map. Inferential reading skills are developed as readers construct relational statements on the concept map to link the newly acquired concepts to prior knowledge. Critical and evaluative comprehension is encouraged in the writing of exposition and discursive argument genre essays according to the knowledge-transforming techniques.

HCP student-teacher dialogue During the HCP lessons there is much opportunity for student-teacher dialogue, a necessary component in the development of scientific literacy. The effectiveness of dialogue in assisting students to speak confidently in the language register of science has been well researched (Lemke, 1990). The period in which the concept mapping activity takes place is particularly appropriate for dialogue.

HCP word processing The principal limitation of the HyperCard software, is that it offers only very limited text editing facilities. There are elementary word processing facilities but no syntactic or semantic guides, such as checkers and document statistics. Therefore a facility within HCP modules for spell checking in specific physics topics, and grammar checking for specific difficulties that have so far been identified, is currently being developed. It is anticipated that these post-writing text editing facilities will enable students to improve their use of scientific language. The text editing will be by prompt only, so that students do not lose control of, or the responsibility for their own text composition.

HCP navigation Each module provides a navigation facility so that students can proceed from the initial concept maps in a number of ways: step by step, backtrack, jump to different sections, go to the start, go to the end or quit at any point in the program. Choice of print style, font and selected text is provided in a modified 'edit' menu while printing of concept maps or essays is accessed within a modified 'file' menu.

Teacher's Manual

The process of development also included the provision of a supporting Teacher's Manual which gives advice to the teacher at each stage of the HCP activities. The manual also provides instructions to teachers for accessing the read-only sections of the program in order to add, delete or alter any sections of the program. The associated lesson pack of overhead transparencies is provided to assist with the teaching of writing techniques, physics concepts, and the use of HCP modules.

TRIALS OF THE HCP PROGRAM

Three cycles

The development of HCP took place in three cycles, each consisting of program development and refinement followed by trials in schools. The program and its capabilities were progressively refined to increase effectiveness and user-friendliness as procedural problems were identified and addressed. The groups were selected from South Australian metropolitan high schools with students from similar low to middle socio-economic backgrounds.

First trial The trial was conducted over a period of two weeks. The results from three trial groups (58 students) were compared with the results from three control groups (58 students) who continued with the regular instruction in the same physics topic. The aim was to investigate change in writing performance before and after the two week trial.

Second trial The trial was conducted over a period of one semester (20 weeks) with six new trial groups (129 students) and three new control groups (52 students) from similar backgrounds to investigate differences in writing performance after successive uses of HCP. As well, a tenth trial group of students with special needs (non-English speaking 'new arrivals') used the program to investigate its suitability for physics students for whom English was a second language.

Third trial This trial is being conducted over a period of two semesters (40 weeks) with eight new trial groups (188 students) and five new control groups (113 students). The long term change in writing in the explanation genre essays is being investigated. At least four pieces of writing over two semesters are being collected in a variety of topics within the physics course over the year. The results of the trial groups will be compared with the control groups. Feedback after each writing activity is being given to both trial and control students.

RESULTS

Results after the first trial

Writing task In the first trial period, one of the three trial groups and one of the three control groups were set the same writing task in 'electricity' at the beginning of the trial and then a similar writing task at the end of the trial. Two other trial groups and two other control groups were set the same writing task in 'magnetics' at the beginning of the trial and then a similar writing task at the end of the trial.

The resulting essays were scored with a first version of the specially prepared assessment criteria for the scientific explanation genre (Cronin et al., 1993) in which the maximum score was 10. Dependent t-tests indicated a significant improvement in mean scores ($p < .001$) for both the trial groups and the control groups. However, as shown in Table 1, the improvement in the trial groups was significantly greater than that of the control groups (independent t-test, $p < .001$). Examination of the essays indicated that the improvements were in the use of scientific concepts within sentence and paragraph structures and in the logical explanation of these concepts.

TABLE 1
WRITING IN SCIENCE

TRIAL GROUPS				CONTROL GROUPS				GROUP DIFFERENCE
Groups	Mean score before	Mean score after	Mean difference	Groups	Mean score before	Mean score after	Mean difference	Difference in group means
electricity n = 15	5.80	8.60	2.80*	n = 16	5.81	6.31	0.50*	2.30*
magnetics n = 43	5.28	7.78	2.50*	n = 33	5.57	5.88	0.33*	2.17*

(*p < .001)

Topic knowledge To ensure that the improvement in writing of the trial groups was not at the expense of knowledge about the topic, a test in physics knowledge on the topic was administered to each of the trial and control groups. The topic knowledge tests in 'electricity' and 'magnetics' were taken from Hewitt (1987) and each had a maximum score of 15. Table 2 shows that the scores of the trial groups were comparable with the scores of the control groups which had spent all the lesson time on regular instruction. The results show that the substantial improvement in scientific writing was gained without jeopardising knowledge and understanding of physics as measured by these tests.

TABLE 2
SCIENCE TOPIC KNOWLEDGE

TRIAL GROUPS		CONTROL GROUPS		GROUP DIFFERENCE
Group	Mean test score	Group	Mean test score	Difference in means
electricity n = 16	11.33	n = 20	11.24	0.09*
magnetics n = 43	11.25	n = 31	11.45	0.20*

(* $p > .05$)

Improvements to HCP after the first trial An important outcome of each trial was the feedback from students and teachers about the use of the HCP modules. There were some initial problems experienced were with the non-repeatability of concept 'buttons' and limited movability of them on concept maps. Navigation pathways also needed improvement to enable students to move easily between the various sections of the program. There were some problems also with some keyboard strokes which led to the deletion of text. The 'help' messages on screen were re-designed to assist students with these problems. There were also some problems associated with the different types of networks that are run at various schools, for example 'userlevel' of HyperCard was set differently on various networks. These and other problems were eliminated by 'scripting' the program requirements into each HCP module.

Results of the second trial

The focus of the second trial was on the perceived value of using the program within a normal semester teaching schedule. Qualitative data were collected rather than quantitative data as non-comparable writing tasks were set by each teacher. This was done by using 'post-HCP' survey forms for teachers and students which were administered at the end of the semester. Additional data were collected from audio-taped interviews with individual students and conversations with teachers. This led to descriptive measures of the effectiveness of the HCP and the results are shown in Tables 3 and 4. The results of these data collections led to further improvements in the HCP.

The post-HCP student survey The post-HCP student survey responses were collected from 113 of a possible 129 students. When asked about enjoyment of the HCP module, the responses indicated that 89% of the students said they enjoyed working with the HCP program for reasons given as: "educational", "different", "fun", "using computers", "I didn't have to work". The 11% of students who said they did not enjoy the program gave reasons such as: "waste of time", "didn't understand", "don't like writing", "boring". The overall enjoyment expressed by the students is one aspect of the success of the program. Other aspects of the effectiveness of the program were assessed with question on a five point response format and the results are illustrated in Table 3.

From the results in Table 3 and from the responses about enjoyment, it can be concluded that students liked the HCP and think that it improved their understanding of physics and writing in physics. Most students said they would use the techniques again, particularly computer-aided concept mapping if they were given the opportunity.

TABLE 3
STUDENT RESPONSES TO THE POST HCP SURVEY

Student responses about the value of HCP for: (n=113)	no help (%)	little help (%)	some help (%)	much help (%)	great help (%)
understanding physics	2	15	45	25	13
writing in physics	10	15	34	26	15
using reading texts	5	25	32	32	6
using model essays	8	25	36	26	5
MEAN (%)	6.25	20.00	36.75	27.25	9.75

Post-HCP teacher survey The seven teachers who were involved in the second trial period indicated their opinions about the effectiveness of the components of HCP shown in Table 4. Six of the seven indicated they would use the HCP program again if given the opportunity. The seventh stated that it took too much time from normal teaching. Of the six teachers, four continued into the third trial period with new class groups while two were unable to take part in the third trial because of redundancy for one teacher and transference from physics for the other teacher.

TABLE 4
TEACHER RESPONSES TO THE POST HCP SURVEY

Teacher responses about the value of : (n= 7)	no help n, (%)	little help n, (%)	some help n, (%)	much help n, (%)	great help n, (%)
concept mapping	---	---	---	6 (86)	1 (14)
reading texts	---	---	4 (57)	3 (43)	---
model essays	---	1 (14)	2 (29)	3 (43)	1 (14)
learning Physics	---	---	4 (57)	3 (43)	---
MEAN (%)	---	3.50	35.75	53.75	7.00

Post-HCP student interviews Another method of assessing the effectiveness of the program was by interviewing a number of students. The interviews were conducted some weeks after the conclusion of the second trial period. A number of student interviews were taped and transcripts made. The interview data revealed that students generally found HCP to be of assistance and contributed to their improvement in writing achievement in physics. Some students stated that they achieved their highest-ever mark for an essay. The interview data indicated that students liked the following features of the program:

- the integration of physics concepts into writing techniques;
- the technique of concept mapping for structuring the writing task;
- the list of concept words, and the 'new concept' provision to enable the correct physics words to be used;
- the facility ('new concept', 'new relationship') to incorporate own ideas into the concept map;
- the informative and motivational reading texts;
- the word processing that gives flexibility for rearranging text;
- the user-friendliness of the program (modified menus).

Further refinements to HCP In response to users' comments and observations made during the second trial several modifications were made to the HCP program. Provision of display boxes was made for definitions of the various concepts with the facility for students to return to these whenever required. Further use of 'return buttons' also increased the multiple pathways facility for students. The 'text style' options were added to the modified 'edit' menu for improved presentation.

Some of the problems expressed by teachers related to the meaning and use of genres in scientific writing and the requirements of each genre. This led to further discussion and refinement of the assessment criteria for the explanation genre. Clear indicators of language usage and concept development within three assessment grades were developed and included in HCP modules and the Teacher's Manual.

The Teacher's Manual was also upgraded and a 'trouble shooting' section was included to assist the teacher using HyperCard for the first time. An 'advanced teacher' section was also added to allow teachers to modify the program to suit their own needs, for example, the addition of new reading texts, writing models and new definitions

Results of the third trial

Essays As each of the pieces of writing is being completed in both trial and control groups, it is graded according the assessment criteria for explanation genre, and individual feedback is being given to the students. Already it is clear that as the students become more familiar with the program, they focus more quickly on the task. Consequently it has been possible to reduce class time for the writing exercise. After repeated use of the program, students can generally develop a concept map in one lesson and type/edit an essay in a further one or two lessons, thus reducing the pressure on teachers' course schedules.

Pathways analysis The pathways analysis is being used to investigate the cognitive processes used by students during the writing process of explanation essays. Preliminary analysis of students' navigation pathways indicate great variety. The complexity of pathways seems to bear a direct relation to the quality of concept maps and essays. Further analysis of the structure of student essays may indicate preferred writing styles. The structure of concept maps also may shed light on the cognitive processes that are used in the knowledge-transforming model for the integration of language acquisition and concept development.

CONCLUSION

The HCP program of physics modules developed and tested in this study is based on a hypertext methodology for the writing of scientific explanation genre essays. Results of the first trial suggest that the program brings about an improved writing performance and the results of the second trial found that students and teachers enjoyed using the program and found it helpful for integrating language acquisition and concept development in the writing exercises. Results of the third trial are being used for further analysis of cognitive writing styles.

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"THE APPROACHING STORM." IDEOLOGY POWER AND CONTROL: THE NATIONAL SCIENCE TEACHERS ASSOCIATION CURRICULUM DEVELOPMENT IN THE USA

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ABSTRACT

This paper examines the ideology of one the best known figures in science education in the USA, and draws attention to the relationship between the political climate and curriculum in national curriculum developments. We are mindful of the forces shaping the schooling of science in Australia, and we present this analysis as an example of the social forces that dominate education both here and overseas. Paramount is our desire to open the door for a socially responsible Australian school science experience.

PREAMBLE

We applaud the efforts of many of our American colleagues in their important and necessary task of revitalizing science education in America. We would argue that from an Australian perspective it is important to understand the processes that result in the production of new curricula, both at home and overseas. With respect to importing curricula we suspect that too often in the past, the information we present here about the National Science Teachers Association's (NSTA) curriculum project, and the issues we argue for, have been absent. Our concern is wholly for Australian science education, that it should promote those ideals that commit Australians to understanding science as a part of society. We seek to promote democratic participation in society and this includes being reflectively critical of its institutions and practices, including science.

For Australia the significance of an examination of an American science curriculum development, lies in part in the answer to the question 'why do curriculum developments from overseas, especially from America, seem so alluring?' To understand this phenomenon a full examination of the political and cultural relations of Australia would be required, and these can only be alluded to here. Our aim is on the one hand to demonstrate the political influence of a particularly power player in the struggle for curriculum reform in the USA, and on the other to indicate the potential educational consequences of that influence. We hope that this study will encourage curriculum developers and researchers to take a more reflective and critical approach towards the underpinning ideologies of curricula from wherever they originate.

INTRODUCTION

Increasingly in this century American culture has come to dominate the English speaking world. Firstly the other English speaking nations and latterly nations as diverse as China and Russia, have come under the direct socializing influence of American culture. In many subtle ways we have increasingly come under the influence of American culture, through film and television for example. The internationalisation of business, too, has had a considerable impact in tuning-in other cultures towards things American.

The extent to which this internationalisation might be responsible for the changes in Australian science education since World War II is worthy of debate. Suffice to say that, curriculum developments in America do appear to have been influential. It could be argued that without these influences, science education in Australia would be much the poorer, and certainly less vibrant and dynamic. On the other hand, raising questions about our national identity is timely, and in the context of education, instructive. In the context of the future of Australian education what is important is a recognition and an acknowledgement of the influences which help stimulate change these include: an understanding of the power relations, and the ideologies underlying curriculum developments. For it is at the level of ideology that the purpose of the schooling of science will be determined: what is to be taught in our classrooms, how it is to be taught, and in whose interests. Our apparent failure to subject past curriculum and teaching innovations to close scrutiny demonstrates a naivety and ignorance of underlying motivations of the processes of schooling in society. In the case of the influence of American science education this failure demonstrates an international aspect of cultural and social reproduction (Bourdieu & Passeron, 1977).

Science curricula are indebted to the reproductive ideologies of their developers and promoters, and are controlled by the dominant social ideology of the time. Science curricula are also subject to the imperatives of the institution of science; indeed they are often controlled by elite groups of scientists. An examination of the social relations from which innovations arise reveals much about power and control in schooling, and about society generally. In America today the struggle both within the Scope, Sequence and Coordination of Secondary School Science (SS&C) project, and between it and Project 2061: Science For all Americans (American Association for the Advancement of Science, 1989) is intense. The former is promoted by the National Science Teachers Association (NSTA), and the latter is a long term project of the American Association for the Advancement of Science (AAAS). The primary focus of this paper is SS&C because its public profile and shorter time span ensures an immediacy of effect. The aims of SS&C are spelt out in the name:

> Scope: A coherent science curriculum should span all six or seven secondary school years and involve all students.
>
> Sequence: (A)ppropriate sequencing of instruction, taking into account how students learn.
>
> Coordination: Coordination among ... (the science) disciplines leads students to an awareness of the interdependence of the sciences and their place in the wider body of human knowledge. (NSTA, 1992, p. 15)

The project's avowed aim is to dismantle the unwieldy U.S. 'layer cake' secondary school curriculum (NSTA, 1992, p. 14). Typically "students study biology in the ninth or tenth grade, then chemistry the following year, and finish off with physics in the twelfth grade" with earth science sandwiched in between (NSTA, 1992, p. 14). This is to be replaced by a study of every science discipline every year. In 1989 Aldridge proposed a model in which biology, chemistry, earth science and physics would all be taught for each of the secondary school grades. Following a simplified Piagetian scheme the emphasis would change from descriptive phenomenological, through empirical semi-quantitative to theoretical abstract (Crow & Aldridge, undated). There is much discussion in the SS&C publications about the spiral approach to the curriculum, whereby students will revisit concepts over a period of years.

It is claimed that SS&C is not a curriculum, but the book, The Content Core: A Guide for Curriculum Designers (NSTA, 1992), has the appearance of a curriculum, even detailing the level at which particular concepts could be taught. It advocates "carefully sequenced, well coordinated instruction of all core science subjects ... each year from grades six through 12" (NSTA Reports, Feb./March, 1993, p. 9). The project strongly criticises present practices, including evaluation methods, the role of textbooks, and pedagogy generally (NSTA, 1992, pp. 13-14).

Large well-funded projects such as SS&C demonstrate many parallels with research and production in science and technology. Funding, cycles of credibility, and institutions all converge through policy decisions, and are features of the nature of the process. Our focus here is an examination of the social relations surrounding the SS&C project, and in particular the power and influence of the originator of the project, in order to see the ideological setting in which the curriculum was conceived.

THE BIRTH OF THE PROJECT: A CONVERGENCE OF RHETORIC

The birth of the project sees parallels with much of the rhetoric applied to science and technology; the "United States must develop its human resources more effectively. Our individual security and national well-being depend on it" (Crow & Aldridge, undated paper, p. 35). Appeals to security and national well being are always popular expressions of xenophobia, especially in the America of the Reagan years. It was the President who stressed security and preached a particular brand of moral values. The education system was seen, as it always is, as an important vehicle by which to inculcate them (see Ronald Reagan's speech to teachers and principals, 1990, pp. 509-512). The rhetoric used is a reminder of the politics of the cold war, and the justification of R&D for defence and a particular emphasis in education.

The concerns expressed over the Japanese economic miracle and the desire to re-assert technological supremacy have been recurrent themes in America during the last decade or so. In 1983 the Federal Secretary of Education, T.H. Bell, released A Nation at Risk, which examined the relationship between education and prosperity. Here the 'risks' were spelled out in stark economic terms:

> The risk is not only that the Japanese make automobiles more efficiently than Americans ... It is also that these developments signify a redistribution of trained capability throughout the globe. Knowledge, learning, information, and skilled intelligence are the new raw materials of international commerce and are today spreading throughout the world (pp. 6-7).

The indicators of risk included international comparisons of student achievement, in which of 19 academic tests across industrialized nations the U.S. was last seven times (Bell, 1983, p. 8). The poor achievement in the international achievement tests was a subject of debate at the AAAS Colloquium, Science and Technology and the Changing World Order (Sauer, 1990). In the period from 1980-1992 there had been over 350 national reports "lamenting the condition of education in America and calling for changes" (Hurd, 1992). In 1989, Bush (1990) again used the poor results of American children in science compared to students in other countries: in "a recent comparison of 13-year old students in the United States and five other nations, America (was) placed ... near last in science" (p. 1217). In America 2000 President Bush's rhetoric of concern is apparent:

> Our country is idling its engines, not knowing enough nor being able enough to make America all that it should be.... Nor is the rest of world sitting idly by, waiting for America to catch up. Serious efforts at education improvement are under way by most of our international competitors and trading partners. (1991a, p. 15)

Science is specifically mentioned in a statement on America's Education Goals (Goal 4) to be achieved by the year 2000: "U.S. students will be first in the world in science and mathematics achievement" (Bush, 1991a, p. 19). The performance required is to be tested against "international achievement tests" (p. 74) and the goals relate to "the level of training necessary to guarantee a competitive work force" (p. 74). The political rhetoric by Bush around this time provided powerful support for the SS&C, rhetoric that was couched in scientific analogy, the need for "a quantum leap forward" (Hurd, 1992, p. 36). In 1989 Bush stated that he intended to double the "National Science Foundation's budget by 1993 to guarantee that America's technology is number one" (Bush, 1990, p. 303). The convergence of rhetoric is nicely summarized in the NSTA's major publication, The Content Core : A Guide for Curriculum Designers, which stated that "The United States is poised, both in terms of resolve and resources to undertake science education restructuring" (1992, p. 14)

According to Bill Aldridge, the long time Executive Director of the National Science Teachers Association (NSTA), discussion about the project began during 1988 (Aldridge, 1992a, p. 13), and the NSTA Reports of Feb./March, 1993, the newsletter of the NSTA, records that the project was launched in 1989 (p. 9). It appears that he was responsible for the project and that it arose from an analysis which he had made of "science education in several countries" (Aldridge, 1992a, p. 13). If, as we suspect, he visited the then USSR, the emphasis on the continuity of learning in each of the sciences year by year appears to have struck home forcibly. Thus armed, the NSTA has been able to propose that students at secondary schools (Years 7-12) should have 6-8 hours of science instruction per week (Aldridge, 1992b, p. 6), similar to the USSR and China. Aldridge states that the National Science Foundation (NSF) showed a great deal of interest in the idea and supplied a seeding grant to enable the planning of a "large reform project" (1992a, p. 18). He reports that among those attending the first meeting were scientists, including a Nobel Laureate. Here we see the NSF once again taking a great deal of interest in school science.

Echoes of the Past

The nation was portrayed to be at risk in 1957 by the dramatic launch of the Russian Sputnik. Sections of the scientific community of America "seized the opportunity with both hands" (Calder, 1970, p. 3). "Phoney statistics about Soviet research and education" (p. 31) fuelled anxiety. After the dog ride in Sputnik II Eisenhower went on television to reassure the nation. Nigel Calder (1970), reports that this was simply an imagined or fabricated technological disaster; in fact, competence was not an issue here but rather military inter-service rivalry. The upshot was a heady period for both American science and science education. The budget for the NSF was trebled, and "science education received a massive injection of federal money under a law significantly entitled the National Defense Education Act" (p. 31).

SCOPE, SEQUENCE AND COORDINATION (SS&C)

While the exact level of funding for SS&C has been difficult to ascertain, the funding for it is extremely large by educational standards. Aldridge reports that SS&C is funded by both the Department of Education and the NSF and that "(s)ome $13,000,000 dollars in Federal money have been invested in the project, along with considerable state and local resources" (Aldridge, 1992a, p. 18). Funding is also coming from the American Petroleum Institute and the Chevron Corporation for both in-service and the production of teaching materials for the science teachers involved, by teachers working with industry scientists at summer schools during the next three years (Lutz, 1993). It is reported in The New York Times (Sura, 1992) that the Houston site (see Figure 1 for a list of the trial sites for the project) received a total of 2.8 million dollars from the Federal Department of Education and the NSF. State Governments may also be involved, a proposal for $2,000,000 per year was submitted by the California SS&C site to enable expansion of the Project.

While the project is coordinated centrally it is being developed with a large degree of autonomy at six regional sites. These are California, Iowa, Puerto Rico, Georgia, Alaska, North and South Carolina and the City of Houston, Texas; we have no information on rationale for the selection of the sites. In 1992, 75,126 students in 343 schools and 1120 teachers were involved, with California having 33,600 students, 228 schools and 665 teachers (SS&C, 1993).

The Project's Director is currently Arnold Strassenburg and he states, in a personal letter, that although there are a number of boards and committees the management is simple: each of the six sites is funded directly by the NSF, each site director answers to the NSF, Strassenburg's Coordinating Office receives its own grant from the NSF, and they are responsible to the NSF. In connection with the SS&C Advisory Board, he notes that this NSTA Board provides him with advice.

POWER AND CONTROL

As the project appears to have been conceived by Bill Aldridge, who as far as the NSTA is concerned represents an important element of bureaucratic stability in an organization of constantly changing elected personnel, we judge that his influence has been crucial to the early direction of the Project. His continuity of tenure as the executive officer of the NSTA has probably enabled him to become well known on the Washington scene. Bill Aldridge, is described in a Scientific American article entitled Teaching Real Science, as an "impatient reformer", a "determined ex-physicist" and as the "force behind the association's curriculum reform" (Beardsley, 1992, p. 102).

Aldridge is a powerful player and has many opportunities to exercise influence. Aldridge now appears to be at "arms length" from the Project except that he is a member of several committees who have input into the Project. In order to understand his potential influence on SS&C it is necessary to follow the trail of committees and the organizational structures surrounding the project and this is shown in Figure 1.

He is a member of the following committees: SS&C Advisory Board (provides advice to the Project Director), SS&C National Coordinating Committee, National Council on Science and Technology Education Guidelines, 2061 and the National Research Council Science Standards Advisory Board. He is known by science teachers throughout the country.

Aldridge's ideology which peeps through as if ashamed from the pages of his papers, is politically crafted to gain support for his Project. His own ideas are largely implicit, with innuendos, in a sea of references to unexamined authorities. He operates by including almost everyone, but his assertions are muddled and in places inaccurate.

His ideology is clearly a variant of objective, value-free science ideology, now widely discredited but still useful to the "military-industrial complex", as Eisenhower called it. Aldridge's model of science appears in the section on "Why do we believe?" (1992a. p. 16). "Scientists believe in theories", he tells us, "only so long as they are successful in accounting for all aspects of the phenomenon". Those of us who have taken notice of the careful studies which have been done in the history and sociology of science during recent decades no longer believe in that myth. Nor, if we have been attentive to recent philosophy of science, do we believe we "create models or theories to account for facts, observations, and empirical laws". Facts, on which Aldridge expounds at length ("How do we know?") are problematic and "empirical laws" are theories. And the central assertion of Aldridge's Project, that teaching should proceed from the descriptive-phenomenological, through the empirical and semi-quantitative, to the most abstract and theoretical (1992b. p. 5) completely ignores all the

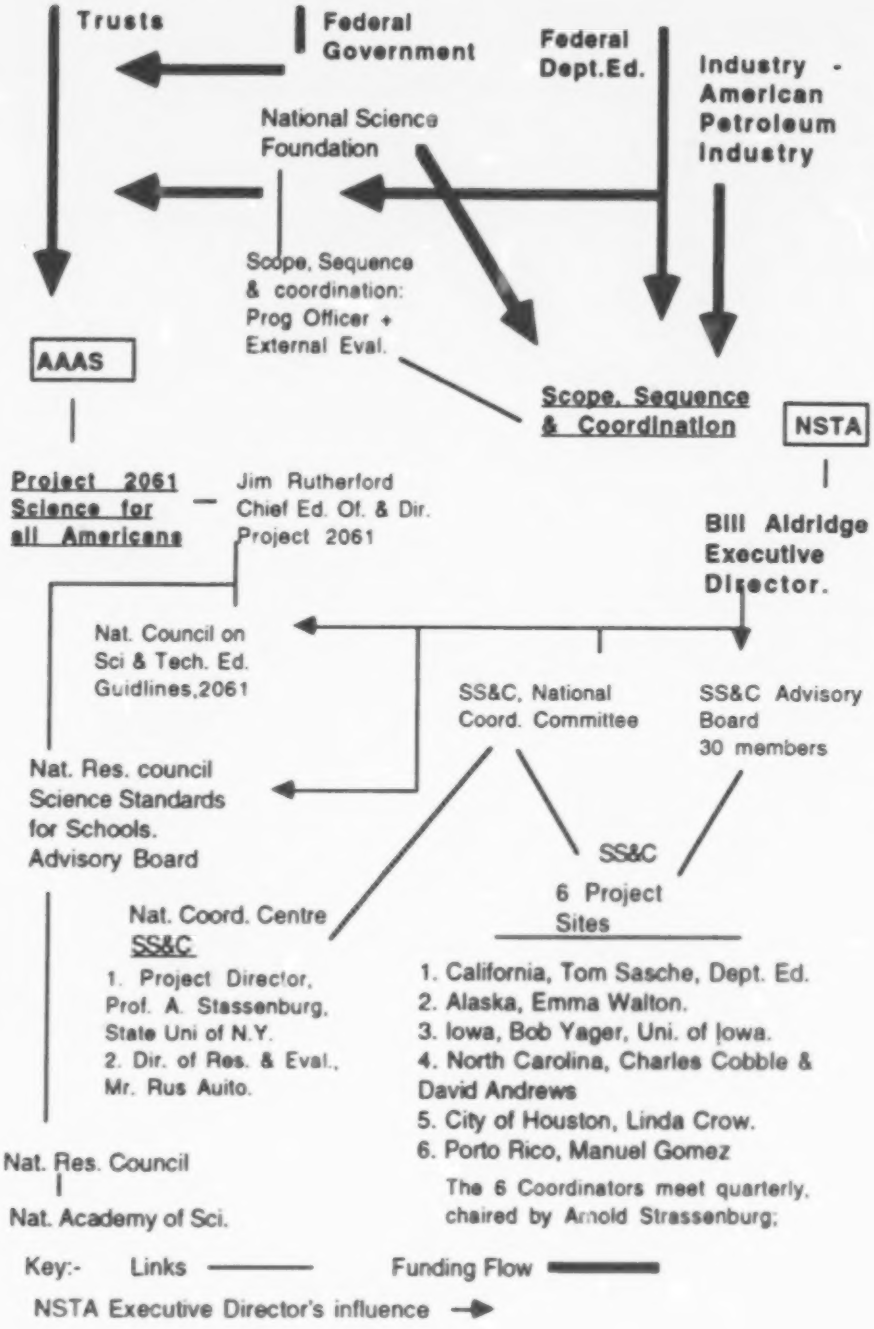
Trusts
Federal Government
Federal Dept.Ed.
Industry - American Petroleum Industry
National Science Foundation
Scope, Sequence & coordination: Prog Officer + External Eval.
AAAS
Scope, Sequence & Coordination
NSTA
Project 2061 Science for all Americans
Jim Rutherford Chief Ed. Of. & Dir. Project 2061
Bill Aldridge Executive Director.
Nat. Council on Sci & Tech. Ed. Guidlines,2061
SS&C, National Coord. Committee
SS&C Advisory Board 30 members
Nat. Res. council Science Standards for Schools. Advisory Board
SS&C 6 Project Sites
Nat. Coord. Centre SS&C
1. Project Director, Prof. A. Stassenburg, State Uni of N.Y.
2. Dir. of Res. & Eval., Mr. Rus Auito.
1. California, Tom Sasche, Dept. Ed.
2. Alaska, Emma Walton.
3. Iowa, Bob Yager, Uni. of Iowa.
4. North Carolina, Charles Cobble & David Andrews
5. City of Houston, Linda Crow.
6. Porto Rico, Manuel Gomez
The 6 Coordinators meet quarterly, chaired by Arnold Strassenburg;
Nat. Res. Council
Nat. Academy of Sci.
Key:- Links
Funding Flow
NSTA Executive Director's influence

Fig. 1 Flow of funds, links and the executive director's inputs into SS&C

work which has shown the way in which theory of various kinds shapes our questions and observations (Cross & Price, 1992). Or would Aldridge simply claim that we are not the independent scientists to whom he looks for "confirmation" before changing his theory? (Aldridge, 1992a, p. 16)?

When Aldridge gives us an example of his pet conception of sequencing, by which he means learning which "moves from concrete experience to abstraction" (1992a, p. 14), he chooses the unfortunate example of the pendulum (p. 17). As Matthews (1992) shows in his paper in Relevant Research, "had Galileo proceeded in this way people would have not surprisingly thought [he] had taken leave of his senses" (p. 191). But he proceeded precisely in the opposite direction and arrived at his 'law'. Or are we again being asked to persuade students that they should observe the results required?

Aldridge's excursion into comparative education is equally misjudged, reminding us of the distortions propagated during the immediate post-Sputnik period of the late fifties and early sixties (Silberman, 1970, p. 169), a period which Aldridge reminds us that he has lived through. First there is the choice of the USSR and China when there are other countries which teach the major science subjects throughout the school curriculum. Both the USSR and China borrowed this feature, of teaching the sciences separately, at different times, from central Europe. Then there are the unwarranted claims that in the USSR the subjects are closely correlated, and that in both countries "all children learn these subjects successfully" (Aldridge, 1992b, p. 4). Such claims can only be justified by ignoring specialist writing on education in these countries, both native and foreign. For example, British specialist on the USSR, James Muckle (1988), translates syllabi which show that in grade 9, students in Biology indeed study circulation of the blood (p. 85) and in Chemistry, the oxygen sub-group (p. 100). But examination of the Chemistry textbook shows there is no mention of metabolic reactions, study being abstractions about the regularities and differences of the main Group 6 elements of the Periodic Table, and introduces students to hybridization in bonding theory (Khodakov, 1986)! Perhaps, he visited a school with enlightened teachers where "coordination" between biology and chemistry occurred.

Aldridge's ideology shows most strongly when he speaks of the Science/Technology/Society (STS) approach. He begins his remarks by citing Harms and Yager (1981) on its relevance to student motivation, and goes on, "It is assumed that this will force consideration of, and motivate learning for, basic concepts, principles, and laws of science, which are then applied immediately to the problem or issue at hand" (1992a, p. 18). Why "force consideration of"? What is the unstated purpose of learning science for Aldridge? The next sentences make that, perhaps, a little clearer:

> Relevance may well be a key component of good motivation, but practical problems are often very complex, and variables identified are almost impossible to isolate and control. Student interest in personal and societal problems is highly individual, and group learning in a classroom setting appears very difficult. The range of problems, issues, and concerns could easily spread into areas beyond the natural sciences, leading to a blurring of distinctions in areas where such distinctions are very important, such as between science and technology, or between science and philosophy and religion. (p. 18)

He then makes a concession:

> Even though the author is convinced for many other reasons that the STS approach is flawed, it nevertheless needs a fair test. For that reason two of our project centers use an STS approach. (p. 18)

One wonders what he means by a "fair test" for STS, and where he will find an "independent science scientists" or science educators to pronounce judgement! Whitehead at the beginning of his famous collection of essays in Adventures of Ideas (1933) observed that it is impossible for even a critical scholar to escape "prejudice" (p. 4) in arriving at judgements. It is worth noting here that Marcia Pearsall, editor of NSTA's publication Relevant Research (1992) for SS&C claims that it is a "collection of research papers and philosophical statements on how secondary school students learn science best" (p. v) but the book devotes less than three pages in a 270 page book to STS, and yet two project centres are using this approach!

The influence of Aldridge's ideology is seen throughout the guide for curriculum planners The Content Core (NSTA, 1992) and the materials being developed at some of the sites, an example being the work done at the Houston Project site, headed by Linda Crow. This site has received further funding from American Petroleum Institute (API). Fueling Around is a grade Eight unit (called Block V, Crow, 1992) and the activities avoid reference to the many contentious scientific and social issues surrounding oil. Significantly, the unit was based on a brainstorming session attended by Crow, Aldridge, teachers and representatives of major oil companies! Here we see Aldridge's ideology at work, the dogmatism of "natural science" strips away not only technology and environmentalism but also the social relations of science, so that Fueling Around is a vehicle for distinguishing between fuel, work and energy!

Aldridge makes many of the enlightened statements one would expect of a person in his position; his comments deploring the widely held assumption that "only certain children are capable of learning science" (1992a, p. 13), and that "science is needed by everyone and everyone is capable of learning and enjoying science" (p. 14) are particularly interesting. Here we see his Achilles Heel, for he is right to assert that science "need not be an unpleasant experience for so many" students (1992b, p. 7), but would his recipe help change things when it seems that he advocates a science curriculum long discredited? It is reported that the 'most common question students ask in science courses is "What good is all this going to do me?"' (Hurd, 1992, 28).

The Iowa SS&C site is headed by Robert Yager, the country's leading proponent of STS, and while space does not permit an analysis of the Iowa STS approach, differences between Aldridge's vision of SS&C and Yager's STS approach to SS&C create an ideological divide. The contrast between Fueling Around and materials being produced by the Iowa centre, for example Station: Earth (Brotherton, et al., undated), is dramatic. Students "become actively involved in seeking information and applying it to real-life situations and issues" (p. 43). What is encouraging here is that within the SS&C Project there are strong forces pulling in other directions and the possibility of the amelioration of the Aldridge proposals (Table 1).

CONCLUSION

America's changing position in the new world order, resulting from the rise of the Japanese and Europeans as economic super-powers, and the collapse of the Soviet Union, has deeply affected the national psyche, perhaps helping establish SS&C as one of the quick-fix solutions. The desire, even need to be seen internationally as the "First in the World by 2000" in science education - regardless of the criteria used to construct the "league table" - is, we suggest, an example of the nation's self-doubts. If there arises a consensus that the curriculum should once again turn to the value-free interpretation that science is produced in a social vacuum, as exemplified by Aldridge's pendulum exemplar, then the more conservative

TABLE 1
THE IDEOLOGICAL DIVIDE BETWEEN ALDRIDGE AND YAGER

Ideology	Aldridge	Yager
Science	value free body of knowledge	embedded in values knowledge is provisional
Science in education	nature of science and the institution of science not questioned	understanding science as a part of society
Educational goals	top in international testing	assist students relate societal issues to daily living
Curriculum	hierarchical structure, central control	planned by individual teachers or cooperative groups
	local initiatives determined by site control	based on local interest, controlled locally

forces in the institution of science will be well satisfied. It is left to Paul DeHart Hurd, the distinguished Professor Emeritus of Science Education at Stanford University, to call into question the underlying issues:

> The criticism of the present science curriculum is that it graduates students as foreigners in their own culture, unfamiliar with the influences of science/technology on social progress and public policy as well as personal and cultural values... For some, scientific literacy is seen as a collection of facts everyone should know...
>
> (For Hurd) A scientifically literate person recognizes the unique character of scientific knowledge and is aware of its values and limitations in cultural adaptation (1992, p. 26).

The lessons to be learnt here include being alert to the social-political aspects underpinning curriculum developments, both in Australia and overseas. We need to adopt a mature approach towards what appear attractive alternatives, even when they have what seems the impeccable pedigree of the NSF! It will require us to discard our cultural cringe and claim the right to voice objections, and where necessary, to criticize the products of others.

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ASSESSING THE PSYCHOSOCIAL ENVIRONMENT OF SCIENCE CLASSES IN CATHOLIC SECONDARY SCHOOLS

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ABSTRACT

Much Catholic school and church rhetoric suggests that Catholic schools possess distinctive learning environments. Research into this aspect of Catholic schooling has been hampered by the lack of an appropriate assessment instrument. By drawing on contemporary church literature, the perceptions of personnel involved in Catholic education and existing classroom environment questionnaires, a new instrument was developed to assess student perceptions of classroom psychosocial environment in Catholic schools. The use of this instrument in 64 classrooms in Catholic and Government schools indicated significant differences on some scales. The distinctive nature of Catholic schooling did not extend to all classroom environment dimensions deemed important to Catholic education.

BACKGROUND

The conceptualization and assessment of the psychosocial environment of classes has become an important field of research (see various reviews of research by Chavez, 1984; Fraser, 1991, in press; Genn, 1984). These reviews have shown that classroom environment is an important predictor of student learning. Other studies have used classroom environment scales as dependent variables in investigating variations in environment across different settings. The particular approach used in most of this research has been to define classroom environment in terms of the perceptions of its inhabitants (i.e. students and teachers). Historically, this idea can be found in the work of Lewin (1936) whose field theory defined behaviour as a change of some state of a field.

The original and continued official view of the Catholic church is that, in some way, religious faith permeates the whole of the curriculum (M.C. Leavey, Identity and ethos in the Catholic school: the elusive variables; unpublished manuscript, Brisbane Catholic Education Centre, 1993, p. 7). This was implicit in the original foundation of the Australian schools last century, and has been restated in the four official papers since the Second Vatican Council (Vatican II) of 1962-1965. Church documents spanning 130 years indicate that the Catholic school was to have an atmosphere consistent with Church doctrines (Geoghegan, 1860; Provincial Synod, 1862, 1869), enlivened by the gospel spirit (Abbott, 1966) and dependent not so much on subject matter or methodology as on the people who work there (Sacred Congregation for Catholic Education, 1977). Bathersby, the present Archbishop of Brisbane, asserted recently:

> It would be a complete misunderstanding to see the Catholic school just as any other, with a daily religion lesson added. Important as the religion program is, it is only part of the difference. The whole atmosphere of the school is one of shared faith where parents, teachers and students come together in prayer and action to live the gospel of Jesus. For the young, the witnesses of faith-filled adults, teachers and parents, provides a lesson and encouragement that no text book can replace. (Bathersby, 1992, p. 2)

From the Catholic viewpoint, education is holistic with the religious dimension interpenetrating the entire school. Conceptually, the notion of having parcels of religion interspersed with parcels of secular knowledge has been strongly rejected. This implies that the environments of science classes in Catholic schools should be different to those in secular institutions. The purpose of this study was to investigate this proposition.

INSTRUMENT DEVELOPMENT

The general procedure adopted was to use existing instruments as bases for the construction of an instrument that would include the important dimensions of a typical Catholic school classroom. This task was simplified by the considerable research efforts in this area previously. Existing scales and associated items needed to be modified and supplemented by new scales so as to tap distinctive environment dimensions. The intuitive-rational approach to instrument development (Fraser, 1986), which relies on the researchers' intuitive understandings of the dimensions being assessed, was adopted. Drawing on the work of previous learning environment researchers, four development criteria were established:

- Consistency with literature. The instrument was to be consistent with literature on the purpose and mission of Australian Catholic schooling.
- Coverage of Moos's three general categories. The final form of the instrument was designed to cover Moos's (1979) three categories of human environments: relationship, personal growth and systems maintenance and change.
- Salience to stakeholders. In order for the instrument to tap salient dimensions, it was considered important for administrators, teachers and students to be involved in the development process. Clearly, this criterion would enhance the instrument's ability to focus on the realities of contemporary Australian Catholic schooling and accordingly contribute to future research possibilities.
- Economy. As teachers face considerable time pressures during the school day, it was considered important that the final instruments be economical in terms of the time needed for administration and scoring.

Using these criteria, a seven-scale instrument with 66 items with responses recorded on a five point Likert scale (Strongly Agree/ Agree/ Neither Agree nor Disagree/ Disagree/ Strongly Disagree) was developed. Table 1 shows the names, descriptions, sources and number of items for each scale.

INSTRUMENT VALIDATION

The assessment of science classroom environment was one component of a larger study involving 2211 students from a total of 104 classes in 32 secondary schools of three types: Catholic non-order, Catholic order and Government (see the following section for further descriptions). Of these students, 1319 were from 64 science classes in the 32 schools. Validation data are presented for the complete sample of 2211 students.

Item and Factor Analyses

Data were subjected to factor and item analyses. Factor analysis of the data from the 66 item instrument supported the existence of 7 distinct scales which were consistent with the 7 a priori scales in Table 1. Item-scale correlations confirmed that all items had been assigned to the appropriate scale and that each item made an appreciable contribution to that scale.

Internal Consistency

Estimates of the internal consistency of the seven scales of the classroom instrument were calculated using Cronbach's alpha coefficient for the above sample. Both individuals (students and teachers) and class mean scores were used as units of analysis (Sirotnik, 1980). Table 2 shows the alpha reliability coefficient for each scale of the classroom instrument using the individual student, the individual teacher and the class mean as the unit of statistical

TABLE 1

SCALE NAMES, DESCRIPTIONS, SOURCES AND NUMBER OF ITEMS FOR SEVEN CLASSROOM ENVIRONMENT SCALES

Scale Name	Scale Description	Source of Scale	Number of Items
Student Affiliation	Extent to which students know, help and are friendly towards each other.	Learning Environment Inventory (LEI) (Fraser, Anderson & Walberg, 1982) Classroom Environment Scale (CES) (Moos & Trickett, 1987)	9
Task Orientation	Extent to which it is important to complete activities planned and to stay on the subject matter.	CES	9
Order & Organisation	Emphasis on students behaving in an orderly, quiet and polite manner, and on the overall organisation of classroom activities.	CES	10
Individualisation	Extent to which students are allowed to make decisions and are treated differently according to ability, interest and rate of working.	College & University Classroom Environment Inventory (CUCEI) (Fraser, in press) Individualised Classroom Environment Questionnaire (ICEQ) (Fraser, 1990)	9
Teacher Control	The number of rules, how strictly rules are enforced and how severely infractions are punished.	CES	9
Interactions	Extent to which teacher-student interactions emphasise a Christian concern for the personal welfare and social growth of the student.	Researcher, with three items from the CUCEI Personalisation scale	10
Cooperation	Extent to which students cooperate rather than compete with each other.	Researcher, with some influence of LEI Competitiveness scale	10

analysis. As expected, alpha reliability coefficients based on class means are somewhat larger than those obtained with the individual as the unit of analysis. The values of the alpha coefficient suggest that each scale of the instrument has acceptable internal consistency for either the individual or the class mean as the unit of analysis.

Discriminant Validity

Table 2 also reports data about discriminant validity using the mean correlation of a scale with the other six other scales as an index. These data indicate that the scales do overlap but not to the extent that would violate the psychometric structure of the instrument. In addition, the data compare favourably with discriminant validity data from recent studies involving several well-established classroom environment instruments (see Fraser, in press).

Ability to Differentiate Between Classes

One-way ANOVAs for classroom environment scales with the student as the unit of analysis and class membership as the main effect showed that each scale of the instrument differentiates between classes. The results of these analyses are shown in Table 3 and indicate that all seven scales differentiated significantly between classes ($p<.001$). The eta^2 statistic, which is a ratio of between to total sums of squares (Cohen & Cohen, 1975), indicates that the proportion of variance explained by class membership ranged from 7% for the Task Orientation scale to 27% for the Interactions scale. In the main, these values allow for educationally meaningful conclusions to be drawn.

TABLE 2

ALPHA RELIABILITIES AND MEAN CORRELATION WITH OTHER SCALES FOR TWO UNITS OF ANALYSIS

(N=2211 students; 104 teachers; 104 class means)

Scale	Alpha Reliability Coefficient			Mean Correlation with Other Scales		
	Individual as unit of analysis		Class mean as unit of analysis	Individual as unit of analysis		Class mean as unit of analysis
	Student	Teacher		Student	Teacher	
Student Affiliation	0.69	0.75	0.84	0.22	0.27	0.32
Interactions	0.90	0.80	0.97	0.29	0.28	0.36
Cooperation	0.71	0.69	0.83	0.28	0.22	0.36
Task Orientation	0.76	0.70	0.90	0.33	0.26	0.32
Order & Organisation	0.84	0.80	0.95	0.33	0.27	0.36
Individualisation	0.54	0.73	0.80	0.15	0.16	0.34
Teacher Control	0.75	0.71	0.88	0.22	0.19	0.28

TABLE 3

ANOVA RESULTS FOR CLASS MEMBERSHIP DIFFERENCES IN STUDENT PERCEPTIONS OF CLASSROOM ENVIRONMENT

Scale	MS Between	MS Within	df	F	Eta^2
Student Affiliation	18.7	8.6	103, 2107	2.2*	0.10
Interactions	199.0	26.7	103, 2107	7.5*	0.27
Cooperation	44.1	11.9	103, 2107	3.7*	0.15
Task Orientation	14.5	8.8	103, 2107	1.6*	0.07
Order & Organisation	50.5	11.9	103, 2107	4.2*	0.17
Individualisation	42.2	11.1	103, 2107	3.8*	0.16
Teacher Control	33.9	9.1	103, 2107	3.7*	0.15

*$p<.001$

DIFFERENCES BETWEEN SCHOOL TYPES

This section briefly describes the application of this instrument in Catholic and Government secondary schools in Queensland. Data from the same 1319 science students used at the instrument development were analysed. These students were from 64 Year nine and Year 12 classes in 32 schools. The schools were classified as Catholic non-order (10 schools), Catholic order (10 schools) and Government (12 schools). Catholic non-order schools are lay administered and coeducational. By contrast, Catholic order schools are either owned or administered by a religious order (e.g. Sisters of Mercy, Christian Brothers). These schools are single sex, with the sample used in this study consisting of five boys' schools and five girls' schools. In each school, one Year 9 science class and one Year 12 multi-strand science class were surveyed. The sample was from metropolitan Brisbane and provincial cities and towns of Queensland and both the schools and the classes within each school were considered to be representative samples of school and subject type.

Differences between the three school types were tested statistically for each of the seven scales. Using the 64 class means on each of the seven scales, a one-way MANOVA was conducted in which the set of seven classroom environment scales constituted the dependent variables and the type of school constituted the main effect. The multivariate test using Wilks' lambda criterion revealed that school type (Catholic non-order/ Catholic order/ Government) was statistically significant ($p<.01$). Univariate ANOVAs revealed only two scales on which there were statistically significant differences in the means, namely, Interactions and Task Orientation ($p<.05$). Tukey's post hoc procedure was used to establish that, for both scales, statistical significance existed between the Catholic non-order and Government schools only. The effect sizes (in terms of the differences in the mean for the school types expressed in terms of the number of standard deviations) were 0.9 and 0.7 for the Interactions and Task Orientation scales, respectively. These findings are summarised in Fig. 1 which is a plot of class mean for each school type for each of the seven classroom environment scales.

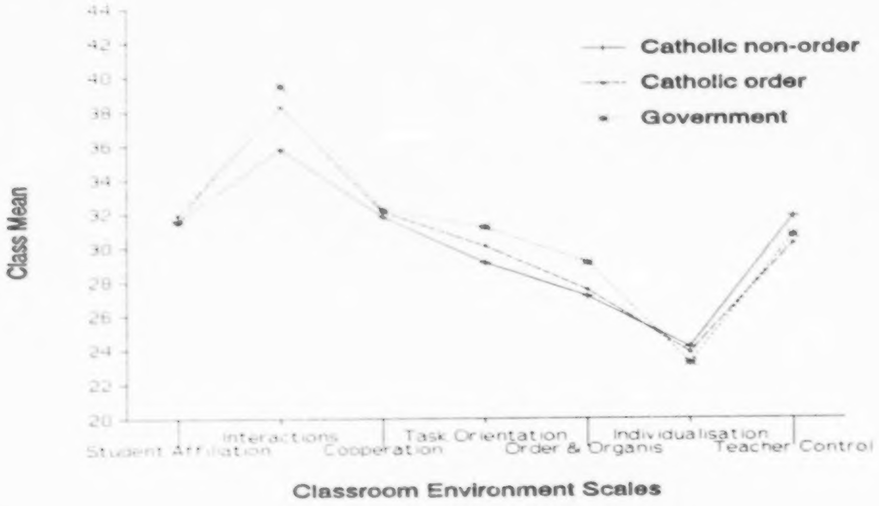

Fig. 1 Responses on seven Classroom Environment Scales for science classes for three school types (N=64 class means)

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The profiles of Fig. 1 reveal some interesting points. Firstly, for the two scales that had significantly different class means, Government schools scored higher than the Catholic schools. Secondly, Government schools scored higher than Catholic schools on Order & Organisation. Thirdly, Catholic non-order schools were perceived to have higher Teacher Control than Government schools. Fourthly, little differences existed between school type scores for Student Affiliation, Cooperation and Individualisation. Fifthly, students in all settings perceived their classrooms as being low on individualisation. A final observation is that, apart from the Interactions scale, only small differences between the class means for Catholic non-order and Catholic order schools were present.

Discussion

Catholic schools are purported to possess distinctive environments. Implicit in such a statement is the view that Catholic schools have a distinctive environment when compared with Government schools. Moreover, the rhetoric of Catholic church literature suggests that Catholic schools should have a more positive learning environment than Government schools. The evidence of this study fails to support this assertion. Indeed, the rhetoric of the literature and stakeholders is at odds with the findings of this study. Based on the rhetoric, one would reasonably expect Catholic schools to be different on at least the six scales of Student Affiliation, Interactions, Cooperation, Task Orientation, Order & Organisation, Individualisation. This has not been the case. The data of Fig. 1 show clearly that the direction of between school type differences is the reverse of that suggested in the literature. A further issue addressed in this study was the difference between the environment of Catholic non-order and Catholic order schools. Folklore suggests that order schools (being more established and permeated by the order's charism) have a distinctive (and superior) environment compared to Catholic non-order schools. The evidence of this study does not support this assertion. The presence of a religious order does not appear to be associated with a distinctive environment. It should be noted that the pooled data of the order schools were from 5 boys' schools and 5 girls' schools. Further data analysis will be conducted in this area, especially in the comparison of the classroom environments of Catholic girls' and boys' schools.

CONCLUSION

This paper contributes to classroom environment research by describing the development, validation and use of a new instrument for assessing classroom environment in Catholic secondary science school classrooms. The final form of the instrument met the four development criteria of consistency with literature, coverage of Moos's three general categories, salience to stakeholders and economy of scoring. The reporting of one application of the instrument illustrated its utility. The instrument is important to Catholic education because its dimensions have been developed to reflect the purpose of contemporary Australian Catholic education.

Clearly, the directions of the differences between school types in this study are not consistent with the literature and are cause for some concern by Catholic school teachers and administrators. Further research is needed to establish whether similar findings exist in other subject areas.

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HOW CAN WE FIND OUT WHAT 3 AND 4 YEAR OLDS THINK? NEW APPROACHES TO ELICITING VERY YOUNG CHILDREN'S UNDERSTANDINGS IN SCIENCE

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ABSTRACT

This paper outlines work in progress on a study which is investigating what children understand about natural and processed materials and how scientific learning on the topic could be extended and reinforced in the home. Four different interview schedules for eliciting children's understanding were developed and tried out. Children's understandings prior to each of the four units, and at the conclusion of the teaching program were documented through individual interviews. Family interviews were also conducted prior to and at the conclusion to the teaching. In this paper the difficulties associated with researching young children's thinking are explored. The rationale for a storytelling context for the interviews is presented, and there is a preliminary discussion on the effectiveness of the methodology utilised.

INTRODUCTION

In the last two years a significant amount of general curriculum development for primary and secondary education has taken place. This can especially be seen as individuals all over Australia have met and discussed draft Profiles and Statements in the different curriculum areas. In science education the establishment of the Science Curriculum and Teaching Program (SCTP) to support the National Science Curriculum Statement and National Profile has been welcomed by those in the field (Curriculum Corporation, 1992).

One of the projects to come under the umbrella of the SCTP is the K-3 Science program, based at the University of Canberra. This project spans the pre-school to Year Three levels of teaching and learning. The program is integrated and holistic in its conceptualisation and will be, when completed, in its presentation. The development of this early childhood science program is supported by research into young children's thinking and learning. This paper outlines the research element of this project in one of the areas of the program being developed, namely natural and processed materials, which is the second strand in the Statement. In particular the paper discusses problems associated with researching young children's thinking in science.

RESEARCH IN EARLY CHILDHOOD

Research into identifying children's understandings of scientific concepts has used a range of interview techniques. Of note has been the interview-about-instance technique (Osborne & Freyberg, 1985), producing a great deal of data on children's understandings of electricity, force, living things, and light, to name but a few. However, this work has been predominantly done with older children who have greater life experiences and a better command of language than the three and four year olds involved in this study.

Research with very young children (under six years of age) is problematic, and obtaining very young children's understandings in science is difficult (Fleer, 1991). Although some creative solutions have been used with children's drawings in science (Hayes & Symington, 1988, 1989), generally little attention has been given to this area.

Eliciting children's understandings depends upon the child's motivation to be involved in the interview or teaching program. Unless young children see some purpose in participating they will simply not become involved. Similarly, if the situation is beyond their social experience then it is likely that they will not fully understand what is being asked, and consequently the results will be questionable. The work of Donaldson (1978) has shown the importance of the social context for interviewing young children. This work has been supported elsewhere (Light, 1986; Wood, 1988; Edwards & Mercer, 1987).

Children's life experiences and subsequent language skills will also influence their ability to give reliable responses and hence may impede their performance during interviews. For example, children may know that smoke and steam are different, but when asked to explain what they can see as water changes from a liquid to a gas, they may use the term 'smoke' because they have not been introduced to the language construct of 'steam' to label it. Hence a good descriptor for that child would be 'smoke'. Yet in a scientific context, this could indicate cognitive confusion.

In order to map young children's understandings over time, lesson sequences being researched must be linked together carefully, so that these young children not only remember what they did the day before, but are able to build upon these experiences and stay involved and interested.

When the method used to elicit children's understandings and the teaching program both make use of concrete materials within a meaningful context or through a form of storytelling, it can be speculated that the data are more likely to be reliable. The study reported in this paper explores the use of storytelling, not only for obtaining children's understandings of natural and processed materials, but as a method of initiating the unit, linking each day for children, and as a way of introducing science activities within a meaningful context. Storytelling was seen as having the potential for effectively addressing the need to engage children's interest in the science topic by providing a context and using language that was within their experiences.

The research element of the study was linked very closely to the teaching program. The research design supported the teaching program and the teaching program set the context for the research. This relationship was mutually beneficial and enhanced the chances of obtaining reliable data.

THE STUDY

One of the strands (major content themes) outlined in the National Science Profile is Natural and Processed Materials. When the research literature into children's understandings of the concepts addressed under this strand (within Levels One and Two) was examined, very little information could be found relating to very young children. However, a wealth of information on older children's understandings was located and used to support the conceptualisation of both the research and curriculum development on the topic.

The research questions

Given the dearth of knowledge about what very young children think about natural and processed materials it was decided to find out firstly their understandings in this area and secondly, how scientific learning could be extended and reinforced in the home.

In order to investigate the second area, a teaching program needed to be developed and taught. Four units of work to support children's learning of the concepts were developed and taught to preschool children (states of matter: solid, liquid, gas; materials and their properties; chemical change: decay, rusting and burning; water: evaporation, dissolving and floating and sinking). These sequences were organised around familiar life experiences such as cooking, and sequences were planned following a modified interactive approach (Biddulph & Osborne, 1984a).

Previous research into parent-school liaison in science education is limited and not related specifically to the link between home and school in children's conceptual development, but rather classroom support (Symington & Hayes, 1987). In this study, however, activities were developed for the home to support the learning sequences in the program. Various forms of communication between the families and teachers were organised and tried out. For example, the weekly newsletter outlined some activities the children had been doing in science during the week and suggested an array of follow-up activities that could be done in the home. It was deemed important to discover what impact the program's science experiences were having on the children through finding out what they shared with their families. It was also considered important to investigate how or if the family was supporting the child's learning through discussions and follow-up activities.

Sample

The families of children attending a child care centre in the Australian Capital Territory (ACT) were invited to participate. A total of 23 children were involved in the teaching program, but due to the flexible nature of child care attendance by children, not all children were present each day.

The youngest child at the time of the study was 2.7 years, and the oldest child was 4.8 years. The average age of the group of children was 3.8 years. Seventeen of the 23 children attended the centre each day whilst the remainder attended part time (ranging from 2 mornings per week to 2 days per week). Many of the full time attenders were absent for more than one day during the time of the study.

Six families were interviewed prior to the commencement of the teaching program. The families of three boys and three girls were involved (children's ages: 2.7 years; 3.3 years; 3.6 years; 4.1 years; 4.3 years and 4.8 years). Five of the families were selected from the full time attenders and one from the part time attenders. The range of children's ages, as shown above, was used as the selection criterion for determining the sample.

Method

Family interviews before and after the teaching program were conducted to determine the home activities and discussions that took place during the five week research period. Each person in a family older than the child attending the centre was interviewed prior to the commencement of the teaching program and two weeks after the implementation of the program. The adults were asked what they thought their child (attending the child care centre) understood about natural and processed materials. It was thought that this would provide more contextual information about the child's understandings of natural and processed materials.

Children's understandings prior to and and at the conclusion of each of the four units were documented through individual interviews. A space of approximately one week to ten days occurred between interviews. The interviews were conducted either in the centre or in a room adjacent to it (except the video based interviews: they were done in a different location) and were done by a familiar adult (usually a member of the teaching staff). All discussions and comments made by individual children were audio-taped and transcribed. The family interviews were done by the Director of the centre at a pre-arranged time.

Four approaches were used to establish contexts for the research and associated teaching programs.

A scientific birthday party (focus: states of matter – solids, liquids and gases) The first interview with the children made use of a book (Two silly chefs tried to organise a birthday party). The book was specifically written so as to elicit views on areas shown by the literature to cause confusion with older children. In Table 1 the alternative views held by children are shown referenced to the specific area used in the book to stimulate discussion and/or teaching activities. The book was read to the children at whole group time, and later the children were asked to comment on their understandings of liquid, solid, gas, melting, freezing and evaporation as it related to what the silly chefs were doing in the story. Full details of the materials used are available from the authors. The pages in the book contained spaces for children to draw pictures and for the interviewer to write down the child's views.

TABLE 1

STORY CONTENT REFERENCED TO CHILDREN'S ALTERNATIVE VIEWS

The literature suggests that children:	**Story content:**
are confused by powders; some children think that because they pour they are not a solid (Stavy & Stachel, 1985).	flour/grinding wheat – making bread; making pizza – grating cheese; cutting up topping; spreading tomato paste.
think that liquids (many types) contain water (Stavy & Stachel, 1985; Jones & Lynch, 1989).	making icy poles from different substances (freezing and melting).
think air is a material (Stavy, 1991; Brook, Driver & Hind, 1989).	decorating for the party – blowing up balloons.
think that water vapour just disappears, goes into the receptacle which contains the water (Bar, 1986; Osborne & Cosgrove, 1983).	making a cup of tea – boiling water
have difficulty with the changes of state of matter: melting, freezing, evaporation and condensation (Cosgrove & Osborne, 1980; Osborne & Cosgrove, 1983; Jones, 1984).	melting chocolate and making icy poles.

Micro worlds (focus: materials and their properties) The second set of interviews was designed to ascertain what children understood about materials and their structure. Research conducted with four to nine year olds in this area (objects and the kinds of materials they are made from) by Smith, Carey and Wiser (1984) indicated that children have some notion of material that is different from the idea of object. However, young children rely upon visual perception to make these judgements rather than reasoning. For example older children are likely to reason that "cutting does not affect the material" (Leeds National Curriculum Science Support Project, 1992, p. 2).

In this study the interviews were conducted through the children drawing a picture of their kitchen in their own pre-made book. The children were asked to pretend they were a mouse moving around the kitchen cupboards talking about what they could see and what each item was made from. As a further prompt an array of kitchen utensils was shown to the children. They were then asked to comment on these, indicating what they were made from.

A watery treasure hunt (focus: evaporation, condensation and dissolving) Three discrete areas were investigated under the topic of water: the water cycle, dissolving and floating and sinking. The first area about the water cycle involved each child being introduced to a puppet and a stimulus picture of a wet weather scene. The children were told that the puppet wanted to go flying, but the weather was as indicated in the picture. Each child was then asked what it would be like for the puppet to go flying through the sky. Follow up questions focused on what is rain, where does it come from, where does the rain go, what are clouds etc. Using similar questions but a different interview format Bar (1986) and Bar and Travis (1991) have shown in their research with five to seven year olds that there is a belief that when rain falls that somebody (possibly God) opens a water reservoir; clouds are made of smoke or cotton wool or alternatively clouds are like bags of water in the sky and when they collide the rain falls out (as cited in Leeds National Curriculum Science Support Project, 1992). Since the children in the study reported in this paper were much younger, it was hoped that the storytelling format used would help the three and four year olds describe their understandings of evaporation and condensation.

The second area of the interview focused on what children understood about dissolving. Research into this area has shown that children hold several conceptions of dissolving (Holding, 1987). Children under the age of eight years tend to focus on the solute only and say it just goes, disappears, melts away, and turns into water (Leeds National Curriculum Science Support Project, 1992). In this study, children's understandings of this concept were acquired through the interviewer extending the story about the flying puppet to a puppet wanting a rest and a drink of sweet water. Each child was then asked to mix a teaspoon of sugar into a glass of water for the puppet. The puppet in story telling mode, asked each child a series of questions relating to what they had observed.

The last area of the interview focused on children's understandings of floating and sinking, and the context was provided through the story telling continuing with the puppet tiring of flying and wanting to go for a boat trip. However the children were asked to help the puppet decide from an array of different materials (e.g. blue tac; wood; plastic; and metal) which item would make a good boat. The children then placed the objects into a water trolley to see if they floated or sank. Children were then asked to comment on any contradictions between what they observed and their previous statements. Previous research by Biddulph and Osborne (1984b) into this area with 7 to 14 year olds indicated that children hold a variety of views about why things float or sink. Using stimulus pictures to elicit children's views, they found that the younger children "did not realise that there could be a single explanation. Their response was to begin giving explanations for individual materials" (p. 122). In many cases children talked about lightness or heaviness without considering other aspects such as size. Andreani Dentici, Grossi, De Ambrosis and Massara (1984) have shown through their work on floating and sinking with six to eight year old children "that the manipulation of appropriate material in semi-structured situations and questions which orient the attention towards certain aspects of the experiment, stimulate the child to reorganise his conceptual system" (p. 242), indicating that children are more likely to integrate aspects such as weight, volume, and shape. This would tend to support the notion that active participation by the interviewee is highly desirable if responses are to be closer to their actual understanding.

The three stage interview on the topic of water used in this study involved puppets, concrete materials and a story format. This interview design was significantly different to previous research with older children, where cards depicting scenes and surveys were commonly used. It was hoped that the active interaction by the interviewees and the familiar storytelling context used in this study was more in tune with three and four year olds' interest levels and interaction style, hence it was thought a more appropriate method of eliciting their understandings.

Teddy bear barbecue (focus: chemical change – decay, rusting, burning) The fourth set of interviews conducted with each child focused on their understanding of burning (both skin and fire), decomposition, rusting, and decaying. Previous research into this area has focused on these concepts from a more sophisticated chemical reaction perspective (Leeds National Curriculum Science Support Project, 1992). This research is outside of preschool children's experience and hence was not useful for guiding the development of this interview schedule.

The children in this study were shown a series of video segments on a TV monitor showing a scene relating to chemical change. The children were asked to talk about what they could see, explaining to the interviewer what was happening. In the post interviews, each child viewed segments of the children's activities during the teaching program which had been videotaped and had been added to the original video sequences. Here the children could see either themselves or their peers using the materials (which related to the focus of the interview). Whilst the video segments did not require active participation in the interview, the post interviews related directly to their experiences with chemical change in the child care centre . It was thought that this alternative method for interviewing children had the potential of revealing some interesting data on the interview process itself.

PRELIMINARY THOUGHTS ON THE INTERVIEWING APPROACHES

Although the study reported in this paper is still in progress it is possible to give some indication of the suitability of the interview schedules for eliciting children's understandings, but this will be restricted here to comment on interviews with children themselves and not include interviews with family members. It is possible to point to several aspects of the method that appear to be linked to its effectiveness.

The first was the ongoing interviewing of children throughout the teaching sequence. Since the children were participating in a four-stage teaching sequence with corresponding child interviews prior to the commencement of each new unit, it was possible to find out something about the children's thinking progressively over the five weeks. Whilst each set of interviews had not been designed to find out children's views on learning involved in the unit prior to the interview, the children did make links between them. For example in the interview on the topic of water, one child responded to the floating and sinking exercise by naming all the objects, outlining what material they were made from, whether they were a liquid, solid or gas and if it would float or sink. Whilst this type of response was not sought, the child gave this information readily. This provided an opportunity to see 'thinking in progress' as the children tried to make sense of the new constructs and their labels during each of the four units of work.

A second aspect was the children's responses to the video segments. When the first set of video segments were shown, the children freely discussed what they were viewing, but it was difficult to know what sense they were making of the video segments. However, in the post interview the video segments from the teaching program tended to encourage children to discuss the scientific ideas more extensively, since they could revisit their learning through reporting upon what they had done in the centre. The video segments which included excerpts of themselves or their peers were powerful in stimulating children to talk about what they understood about chemical change.

The book that was used to elicit children's understandings of solid, liquid and gas proved to be very successful. With the use of the book, children's comments made at group time with regard to changes in the state of matter could be better understood when individuals were interviewed. The book provided the opportunity for the children to express themselves either orally or pictorially in a more extended manner than was possible during whole group discussions.

The storybook mode encouraged some children to tell the interviewer what the silly chefs were doing wrong and what they should have done. As a result of the increased opportunity for dialogue, more data were collected from each child in response to each scientific idea. With young children, often the responses are short with little supporting contextual dialogue which is essential for trying to work out what children mean. The interview data collected was significantly richer and easier to interpret than is usual with three and four year old children. Similarly, the children's responses to the storytelling of the flying puppet and the children pretending to be a mouse in their kitchen also yielded more comprehensive data. However, it was not as rich as that obtained from the storybook.

In the teaching program, the children had the opportunity to be involved in each of the stories told or read through either retelling or dramatising the stories or through drawing pictures of their understandings. This linked well with the research component of the study, since the storytelling mode of the interviews tended to be seen as an extension of what they were already doing, rather than as a discrete activity. Overall, it seemed that the children's responses were more expanded, clearer and more specific than is usual with three and four year old children. It would seem that the storytelling mode used for the child interviews proved to be reasonably helpful for eliciting children's understandings of natural and processed materials. The storybook of the three silly chefs tended to be the most successful, since it provided the opportunity for children to respond in two ways: explaining the incorrect actions of the silly chefs and what they should have been doing.

SUMMARY

Research in science education with children under the age of six years is limited in scope and volume. As a research community we have a great deal to learn about how best to ascertain young children's understandings. Children's life experiences, language skills, interest level and sense of social context influence how they respond in an interview situation. As a result, creative procedures need to be developed if we are to find out what children understand.

A number of approaches were developed in this study to provide an appropriate context, both for the research and for the teaching program. There are indications that the approaches used have resulted in more effective eliciting of children's understandings in the four different areas.

There need to be further methodological developments in researching very young children's understandings in science before we can have confidence in the data that we collect. It is hoped that the discussion in this paper will encourage dialogue about this neglected area in early childhood science education.

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DEVELOPING CONCEPTIONS OF FOOD AND NUTRITION

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ABSTRACT

This paper describes an investigation of concepts that various groups hold about food and nutrition. Groups investigated were students in Years 4 and 8, university students in a BEd (primary) program and parents of the Year 4 students. It was found that for many important concepts relating to food selection, the basic ideas of each group were surprisingly consistent, despite the influence of formal education. In particular, misconception about energy and its role in nutrition and particular food groups was an important finding. Implications for school and community education are drawn from the results.

INTRODUCTION

The way we use the term *food* in everyday language depends on the context. In conversation we speak of food and drink as separate classes and distinguish between meals and snacks. There are also more subtle aspects to the way in which we use language which help shape our ideas about food. For example, we add salt to food which suggests that salt is not a food. Similarly, the statement that we fry food in oil suggests that oil is not a food and will not become part of the food when it is prepared. The very notion of food preparation suggests that something is not a food until it is ready to be consumed. Likewise talking about fibrous foods may seem to refer to dietary fibre and lead to confusion.

Formal instruction about food and nutrition begins in primary schools and is extended in the areas of health, science and home economics in the secondary school. Students also receive competing information from a variety of other sources including the home, radio, newspapers, community education programs, magazines and television. In this regard it is important to keep in mind the relative weightings of these sources of information. In terms of time, formal instruction is relatively unimportant. Fortune and Blecharczyk (1983) have also cautioned that knowledge of food and nutrition may not translate into appropriate behaviour. There is much information available about students' understanding of concepts which scientists see as central to the study of science. However, there is relatively little known about students' understanding of concepts such as food and nutrition which are central to their well being and how these have developed. The prime purpose of this study was to address this issue.

Textbooks used in schools describe food in a variety of ways. Barker (1985) has argued that this reflects lack of an agreed definition of food by scientists. Barker and Carr (1989, p. 53) claimed that in printed materials available to students, "Energy-rich materials (carbohydrates, fats, proteins) are always classified as food but the definition is often extended (in decreasing order of frequency) to minerals, vitamins, water and roughage." Roughage is not usually regarded as a nutrient since it does not break down in the digestive tract. However, in the everyday context, roughage is treated as an essential part of the diet and described as such in the nutritional information included on many food labels.

Barker (1985) interviewed a sample of 8-17 year olds (n=28) in New Zealand and found that many had a restricted and context-dependent conception of food. Ferrer, Leong, Lee, Hill and Francis (1990) also investigated ideas about nutrition held by children in Year 4 with similar results. The present cross-sectional study explored changes in conceptions of food and nutrition from primary school to adult and builds on this earlier work and that of the authors (Francis & Hill, 1992).

PROCEDURE

Individual students were interviewed using a series of picture cards as stimulus material to probe their ideas. Students were asked which pictures showed:

- examples of food (Question 1)
- substances which could give them energy (Question 2)

After the students had made a response to each picture they were asked to provide a reason. This reason was probed to ascertain whether their answer might be different in some contexts. In addition, students were asked:

- whether they would get more energy from a spoon of table sugar or from a spoon of watermelon (Question 3).
- which of the ingredients used to make a fruit cake were foods (Question 4)

The ideas that university students and parents held about these same issues were ascertained by means of a parallel questionnaire. The questionnaire for university students contained four further questions. Question 5: How would you classify various foods by level of dietary fibre? Question 6: What happens to the fibre content in each of a range of changes associated with preparation and cooking? Question 7: How much dietary fibre is needed each day? and Question 8: Complete the sentence . . . Dietary fibre is . . . .

Subjects

A random sample was drawn from students in Year 4 in a large suburban primary school in Wagga Wagga and from Year 8 in the high school to which almost all the children from this primary school enrol. The Year 8 group had recently completed a 4 week science unit on food and digestion. The adults in the study consisted of parents of children in Year 4 who responded to a questionnaire sent home from the school and first year teacher education students at the local university. Some of the parents and students were subsequently interviewed to ascertain the reasons for their responses. It was presumed that parents represented adults with a particular concern for nutrition.

RESULTS

The results obtained in this study are summarised in Tables 1-6.

Comments in response to Question 8 "Dietary fibre is ... " included:

Undigestable roughage that gives you energy.
Essential for building body tissue.
Essential for daily needs (3).
Internally healthy (3).
Undigestable matter which pushes food through (5).
something that keeps the digestive tract healthy (5).
an aid to digestion (5).
the amount of food mass in food apart from water.
food that is healthy (2).
a classification of food (3).
involved in free movement of solids in the body.
regulates body processes (2).
prevents constipation (2).

TABLE 1
PERCENTAGE RESPONDING YES TO QUESTIONS 1-2 BY YEAR 4 STUDENTS (N=20), YEAR 8 STUDENTS (N=22) UNIVERSITY STUDENTS (N=53) AND PARENTS (N=20)

Picture	Question 1 Examples of Food?				Question 2 Source of Energy?			
	Yr 4	Yr 8	US	P	Yr 4	Yr 8	US	P
vegetables	95	100	98	100	95	68	82	80
icecream	90	77	93	45	90	41	56	60
lollies/confectionery	90	73	93	20	90	50	62	70
cake	100	86	94	55	100	41	40	65
chicken	100	91	98	100	100	59	67	65
pineapple	100	91	98	95	100	50	87	75
coffee with sugar & milk	10	27	71	25	10	23	25	35
water	15	27	53	35	15	45	21	15
milk	20	27	87	95	20	45	55	75
cooking-salad oil	0	9	49	15	0	0	16	25
table salt	10	23	60	5	10	13	4	5
bread	90	95	98	95	90	59	85	70
alcoholic beverages	-	-	47	5	-	-	29	30
dietary fibre	-	-	58	-	-	-	26	-

TABLE 2
PERCENTAGE RESPONSES OF YEAR 4, YEAR 8 AND ADULTS ON QUESTION 3

Which would give more energy?	Year 4	Year 8	US	Parent
sugar	30	68	81	80
watermelon	70	32	19	20

TABLE 3
PERCENTAGE OF PARENTS (N=20) AND YEAR 8 STUDENTS (N=22) WHO CONSIDERED SPECIFIC INGREDIENTS AS FOODS IN RESPONSE TO QUESTION 4.

Ingredient	Year 8	US	Parents
butter	68	81	90
dried fruit	95	95	100
eggs	77	96	100
flour	41	84	80
salt	9	60	20
sugar	59	-	85
spice	0	55	10

TABLE 4
PERCENTAGE RESPONSES OF UNIVERSITY STUDENTS TO QUESTION 5.

Food (with % fibre for the benefit of the reader)	Level of Dietary Fibre		
	Low 0-2%	Medium 3-6%	High >7%
bread (wholemeal) - 4.0%	0	16	84
carrot (raw) - 3.1%	4	56	40
celery (raw) - 1.2%	9	50	41
corned beef - 0%	59	32	8
dates (dried) - 4.8%	6	44	50
muesli - 12.0%	2	9	87
pineapple (fresh peeled) - 1.2%	17	44	39
soy beans (dried) - 20.0%	13	44	43
wheat flakes (eg weetbix) - 11.0%	4	22	74

TABLE 5
PERCENTAGE RESPONSES OF UNIVERSITY STUDENTS TO QUESTION 6.

Change	Amount of dietary fibre		
	decreased	stayed about the same	increased
new potato is wrapped in foil and cooked in microwave	7	87	5
a piece of pineapple is pulped in a blender	13	81	5
a tomato is placed in boiling water for a minute and the skin peeled	94	4	2
fresh dates are dried	22	51	27

TABLE 6
PERCENTAGE RESPONSES OF UNIVERSITY STUDENTS TO QUESTION 7.

Grams of Fibre Needed in a Day	% Number (n = 32)
0 - 10	12
10 - 20	20
20 - 30	20
30 - 50	4
50 - 100	0
100 - 500	36
>500	8

DISCUSSION

The units on food in the NSW K-6 Science and Technology syllabus include food technology and general nutrition. All secondary school students come in contact with nutrition education in science, health and for some in home science. Nutrition education seeks to change eating habits as well as increase the knowledge of nutrition (Fortune & Blecharczyk, 1983). This distinction is useful when exploring the knowledge people have of nutrition.

The respondents in this survey cover a cross-section of the population at various ages and educational levels. Results showed broad agreement that vegetables, fresh fruit, chicken and bread are foods which are important in the human diet. At a broad view the health campaigns and education programs seem to be successful in a classification of 'healthy' vs 'non-healthy' foods. Comments made during the interview clearly demonstrated however that there was little understanding of how much of these foods is needed or why they are required in our diet.

There were obvious differences between the four responding groups. Ice cream, lollies and cake were classified less often by parents as food than by the other 3 groups. They were described as 'junk' by parents and as such not considered food. The Year 4 students treated question 1 and question 2 as identical. It seemed that if food is good for you and/or tastes good it must provide energy. The low response of parents and to some extent the Year 8 students that these junk foods don't provide energy is an interesting feature of the results. This, combined with the high energy rating of vegetables and the low energy ratings given to salad, oil and alcohol, provides an interesting picture of the link between energy and food.

Solids are more likely to be regarded as foods than are liquids by all groups with the exception of adults who generally considered milk a food. Things that are added in a small amount (salt, herbs, spices) are generally not seen as food.

Table 2 indicates that Year 4 students responded quite differently from adults, while Year 8 students fell in between. The Year 4 students tended to argue that watermelon was a fruit, so it was good for you. If it was good for you it would provide more energy. Sugar is bad for you so it doesn't give as much energy.

The results in Table 3 indicate that the status of an individual ingredient is perceived independently of the part it played in production of the food. Those who did not regard flour as food usually argued that you would not eat flour on its own or that it simply fills up the spaces between the food bits in the final product.

Results in Tables 4 and 5 generally showed some understanding of the fibre levels in foods and the fact that it usually remains fairly constant despite processing. The point to highlight from Table 4 is that a significant number of University students put carrot, celery and pineapple in the high fibre group. Interview data revealed a link between "stringiness" and "high in fibre" (e.g. "Yes, I would consider corn beef high in fibre because it is often stringy".). Wholemeal bread was also over-rated in terms of fibre but for a different reason. Here the reputation of a whole food with all the grain was the factor.

Table 6 reveals a disturbing lack of quantitative information. In many cases the increasing importance given to fibre in the media seems to have indicated to students it needs to be a significant proportion of the total daily intake for students. It would appear the percentages given in Table 4 meant little to the students when answers to low, medium and high were translated into answers they provided in Table 6. Students had a notion that roughage in some way is good for you (energy, digestion, prevents constipation etc.) however little attempt was made to describe the nature of fibre. One student used the word cellulose and one student distinguished between soluble and insoluble fibre.

CONCLUSIONS

The reasons given to explain and justify particular responses enable some inferences to be made about the conceptual frameworks used by respondents. Such an analysis revealed the existence of a variety of schemata (Howard, 1988) relating to food and nutrition. Table 7 links the inferred schema and some examples of evidence by respondents.

It would appear from this study that people operate using broad schema to provide decisions about food and nutrition. Concepts such as "good for you", "well being" and "healthy" are arrived at from a conglomerate of ideas. The ideas seem only marginally affected by school. The language used by the Year 8 and University students did seem, on the surface, to be more technical than that used by Year 4 and parents. This would reflect school influences. However, there was little evidence that their fundamental knowledge of food and nutrition was very different.

The concept of energy seems particularly important as it seems to pervade the way nutritional information is interpreted. Carr et al. (1987) discuss the various ideas teachers and students exhibit about energy. It appears energy is seen as a "goodie" - drawn from such contemporary metaphors as "energy conservation", "running out of energy" and traditional metaphors of energy linked to people: "an energetic person", "healthy people have a lot of energy". Further they highlight the failure of people to distinguish between energy and fuel: a pertinent issue in the context of food. The other set of metaphors relating to food are "healthy foods" and "good foods". As Fortune and Blecharezyk (1983) indicate, dietary habits seem to be described by people in terms of food selection rather than nutrient status.

Juxtaposition of ideas about energy and food seems to provide a broad scheme something like "if it is good for you it has lots of energy". Hence the reason given in some cases for watermelon having more energy than sugar. Melon is good for you (it's natural), sugar is bad for you; therefore watermelon has more energy. Even at the adult level this scheme is maintained. The responses for vegetables being high in energy, while responses for lollies, cakes and particularly oil being low energy seem to be related to the early frameworks of Year 4 students.

The work with University students on fibre reveals similar kinds of broad schemata. Fibre is being increasingly linked to general well being and good health. A significant number of students place fruit and vegetables in the high fibre group. The link indicated here (and confirmed through follow up interviews) was that foods which are good for you (red meat is bad for you - so low in fibre - answer correct, explanation incorrect) must be high in fibre.

IMPLICATIONS

This study has revealed a variety of ideas about food and nutrition held by children and adults. We considered it would be surprising if they arrived at the same ideas considering the competing messages they receive. There were, however, common ideas about the relationship between food and energy. In addition it appears that the ideas promulgated in advertising and health campaigns were used to interpret specific instances. The other common theme to emerge from follow-up interviews was that the Year 8, parents and University students interpreted simplistic food tests in secondary school to conclude that most foods only contain one component e.g. meat contains only protein, potatoes only starch, or TV advertisements in the same way: red meat contains iron, milk contains only calcium.

TABLE 7
INFERRED SCHEMA AND SOME EXAMPLES OF EVIDENCE BY RESPONDENTS.

Schema	Evidence
Foods are things which are chewed.	Water is only a food when it is in ice blocks. If you can't chew it, it is not a food. Milk can become food if you turn it to cheese. Liquids are not food. Digestion makes food liquid so it can be absorbed.
Not all things we consume are foods, only what is good for you.	Watermelon has more food value than sugar so it gives you more energy. Junk food is not food - it is bad for you. Highly processed 'foods' are not really food. You get sugar from natural foods so you don't need sweets or cakes which are not really food.
Only foods which are good for you provide energy.	Chicken, fruit & vegetables are proper foods and give lots of energy but cake, sweets & ice cream are not & only give some energy. Bread and milk have natural energy. Healthy foods give more energy because they contain vitamins & minerals.
Most foods only contain one important nutrient.	Milk contains calcium, fruit has vitamins, vegies have minerals and meat has protein. Chicken has protein & bread has starch - we tested them at school.
Natural foods are healthy & have high food value.	Bread & milk have natural energy. Sugar is bad for you and watermelon is good as it gives you more energy. Sugar gives you most energy over a short period but energy from watermelon lasts longer so it must have more total energy.
Things which are added to or used in the processing of food are not foods.	Cooking oil is put in to our food so it is a food but salt is not because we put it on food. Cooking oil and salt are not food - they help to cook food.
Foods are either good or bad for you.	Sugar is bad for you & watermelon is good so it gives you more energy.
Healthy food contains fibre.	Fruit and vegies are better for you than bread because they have lots of fibre. Healthy foods like cereals and vegies have fibre. Foods bad for you like fats and oils don't have fibre.

This situation has a number of implications for those directly involved in nutritional education and school teachers. They include:

* development of the idea that most foods contain a range of nutrients (not just protein or carbohydrates etc. indicated by standard school food tests).
* people need quantitative information not just qualitative information ("eat more fruit and vegetables"; "eat more fibre" the basis of present campaigns become linked and provide no basis for constructing a diet).
* providing situations where students are asked to interpret the global ideas from advertisements , magazines etc, as they relate to balance in a diet - there appears to be a lot of isolated pieces of information that need linking together so that a complete view of nutrition is obtained.
* advertising about food should be analysed by students and interpreted in a whole diet context - fibre is interpreted via the Kellogg's advertisement on "All Bran", Milk provides Calcium, Red meat provides iron, etc.
* students need lots of activities relating to diets, food information and their own daily intake - computer simulation and data base work could provide both enjoyment and a medium for constructing realistic understanding.
* energy as a concept should be related to diet and nutrition as a way to help work through the misconceptions students have. This personalised context of energy may help overcome some of the reported misconceptions about energy and provide a better way of interpreting food quality.
* the present approaches to teaching about nutrition in schools fails to change ideas people have. We need new approaches in science to assist children to interpret and link the mixed messages and individual pieces of information they receive. Constructivist approaches which begin with what children already know seem imperative.

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TEXTBOOK REPRESENTATIONS OF SCIENCE-TECHNOLOGY RELATIONSHIPS

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ABSTRACT

One way of viewing curriculum content is to regard it as *text:* i.e. as a collection of narrative and argument which helps shape learners' views of the world. School and university textbooks form part of that collection. At university level, texts encountered by future teachers help shape views of the discipline which may be transmitted to later generations of school learners. This paper is concerned with how the relationships between science and technology are portrayed in school and university textbooks. Criteria are offered for evaluating these portrayals, and examples are presented of material which meets (or fails to meet) these criteria.

INTRODUCTION

Why be concerned about science-technology relationships?

There is growing interest around the world in improving the quality of both science and technology curricula. In many cases, developments in these fields are occurring separately, but many educators are arguing that closer links ought to be forged between the two fields. In England, the Royal Society for the Encouragement of the Arts, Manufactures and Commerce (RSA) has been critical of school curricula which permitted learners to acquire knowledge of particular subjects without equipping them to use that knowledge for practical purposes, and called for more emphasis on **capability**, a "culture of doing" (Burgess, 1986). One of the commissioned papers for the DEET Discipline Review (Lowe, 1989) provides a thoughtful account of the implications of the relationship between science and technology for undergraduate science education and teacher education. In various places in the report of the Review (DEET, 1989), there are calls to make school science curricula "more technological and humanly relevant" (p. 47), to include more technology content in undergraduate science courses, to include studies of science, technology and society in initial teacher education curriculum studies (p. 53), and to provide short courses for teachers on "novel topics such as biotechnology, nuclear power...and chemical wastes and their disposal" (p. 59) in either award courses or independent professional development programs.

The issue of science/technology relationships has some practical consequences, for individuals and for society. Subject choices at school for those interested in technological careers such as engineering are frequently based on a belief that "academic" subjects (mathematics, physics) provide a better foundation than more practically-oriented studies. Requests for government funding for scientific research are sometimes justified on the grounds that they may lead to technological outcomes, and hence economic benefits.

Curriculum as text

One way of thinking about the curriculum is to regard it as spoken and written *text*, as a collection of narrative and argument, as a set of story-lines that we offer our students. Sometimes these are based on knowledge that stands up to academic scrutiny; sometimes they are simplistic, partially true versions of a more complex account; sometimes they are myths, indefensible when subjected to careful scholarship, but powerfully persuasive nonetheless. Printed material, especially the textbook, is one contributor to this collection (parents, teachers and the media are others).

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The present article focusses upon the ways in which the relationships between science and technology are portrayed in university and secondary school science textbooks. It will argue that although science texts frequently mention technological artefacts (often to illustrate scientific principles), they generally do so in ways which fail to explain how technology influences science or to discuss the nature of technological capability. Such textbook presentations are inconsistent with the educational efforts of institutions like the RSA who seek to integrate knowledge and practical action.

Criteria for evaluating text representations

Technology and science overlap in many ways, more so in modern times than in the past, but they are not identical fields of endeavour. The terms *technology* and *science* each have various connotations, and their meanings vary across cultures and in differing historical periods. In general, however, *technology* is used here to refer to the artefacts, materials and systems which humans design, make and utilise to meet their needs and desires; *science* refers to systematic attempts to investigate, explain and report observed phenomena in ways that promote better understanding.

The present paper examines the story-lines presented in various university and school texts about the nature of the relationship between science and technology. The following generalisations are offered as criteria for evaluating whether a particular text provides a faithful portrayal of their relationship.

Technology is historically prior to science. Technology began with the evolution of the human species, whereas science is a much more recent phenomenon, about 2500 years old. Even when an artefact and a scientific principle are related in some way, the development of the artefact has frequently preceded the formulation of the principle (Gardner, 1993).

Technology is ontologically prior to science. Technology does not merely precede science in the chronological sense; it can also be considered as a necessary precursor to science. The notion that tools and measuring instruments are essential to the progress of science is of course widely accepted and uncontroversial. What is less widely recognised is that such artefacts allow scientists not only to observe the world, but also to conceive the world. Nutcrackers, clocks and pumps were necessary for the emergence of the principle of the lever, modern conceptions of time, and the theory of circulation of the blood. This is a materialist view of the history of science and technology which emphasises the necessity of the prior development of practical skills and inventions for the subsequent evolution of scientific thought. Ihde (1983) argues that the opposing, conventional idealist view generates an interpretation of the history of modern science and technology in which the dominant events are ideas (e.g. the revival of the Greek scientific spirit leading to the Renaissance and the discoveries of Galileo, Kepler, Copernicus and Newton). A materialist story-line, in contrast, would give adequate recognition to the important contributions of technologists (e.g. the inventors of medieval clocks, farming implements, windmills and waterwheels) to the subsequent growth of science.

Technological and scientific capabilities are not identical. Technology involves designing, making and evaluating artefacts, materials and procedures, to meet human needs and desires. Technological development may draw upon scientific knowledge, but this is not a necessary condition in all cases. Even when technology does make use of scientific knowledge, the process of application may be exceedingly complex and require many practical skills which are not necessarily part of the repertoire of science, a point elaborated in an earlier paper (Gardner, 1992).

Technology and science, especially in modern times, engage in two-way interaction. Although it is certainly true that many modern technologies are based upon earlier scientific research, it is also true that many scientific discoveries have been made as a consequence of developmental work done for technological motives. In some modern fields (electronics, computer hardware, genetic engineering), the interaction between scientists and technologists is so close that it is difficult to untangle their respective contributions.

CASE STUDIES OF TEXT MATERIAL

A range of story-lines

All texts are of course selective, a few hundred pages chosen from the millions of pages that have been or could be written in any scientific field. Authors make choices about which topics to include, and which to leave out, about depth of treatment, about illustrations and exercises and so on. Whatever choices are made, the text is not merely a catalogue of scientific facts and principles: it is a representation of the voice, the ideological position, the construction of reality, the *story-line*, of the author.

School and university science textbooks present a wide range of story-lines about the science-technology relationship. At one extreme, there is the "pure academic science" story-line, where science is on-stage and technology is off-stage, or at best given bit parts. (The stage-craft metaphor is being used quite deliberately here as a way of summarising the various textual treatments.) Some books give technology a strong supporting role, in which technology provides useful instrumentation *for* science, or produces useful artefacts whose workings can be understood *in terms of* science; however, science still occupies centre stage throughout the performance and the character of technology remains undeveloped. Still other books give technology and science joint star billing, but these are very rare.

In the case studies which follow, all but the first of the *university* texts cited have been prescribed or recommended for use in undergraduate science courses at Monash University.

Serway and Faughn (1992)

This text is used as a reference for some introductory physics courses at the University of Melbourne. Its target audience is "students majoring in biology and pre-medicine... health, environmental, earth and social sciences" (p. v). It is an impressive book: comprehensive (34 chapters and more than a thousand pages), beautifully presented (300 colour photographs) and up-to-date (e.g. the physics of laser printers and magnetic resonance imaging). It presents the human aspects of physics by including biographies of physicists, some accounts of the history of science and several interviews with famous contemporary physicists. Environmental concerns such as nuclear reactor safety are discussed.

The authors' approach to technology is one which is common to many science texts. The objective is explicit: to "strengthen an understanding of the concepts and principles [of physics] through a broad range of interesting applications to the real world" (pp. v-vi). Dozens of technological artefacts are described, from Hero's engine through to computed axial tomography (CAT-scanners). The story-line is invariably presented in the same way: the artefact is used as an illustration of the laws of physics. For example, consider the treatment of the photo-copier (pp. 544-545). (Its invention has been mentioned in an earlier paper: Gardner, 1990.) The text provides a succinct account of the "heart" of the photo-copier, the photo-conductive selenium drum which is uniformly charged, partially discharged by the action of light and then coated with toner which adheres to the charged parts of the drum. Two sentences refer to the grant of a patent to Chester Carlson in 1940 and the launching of "a full-scale program" by Xerox seven years later, implying that the development of the innovation was not a straightforward matter. (In fact, 22 years elapsed between the discovery of photoconductivity and the production of the first commercial photocopier.) There is nothing in the text to indicate the ways in which relevant scientific knowledge was fed into the design and making process, nor any hint of the enormous obstacles that had to be overcome. One might surmise that the intended story-line is that physics is of practical value, and that it helps us to understand one aspect of an innovative machine. The artefact is on stage, but mute: we learn nothing about its character from this brief appearance.

Bueche (1975)

A college physics text by Bueche (1975), written for physics and engineering students, is unusual in that the author explicitly outlines his views on science-technology relationships. In his preface, Bueche writes of the "interlacing of science and engineering" in the development of civilisation. He views these as fields as engaging in two-way interaction:

> In theory, the scientist discovers the laws of nature. These laws are then used by the engineer to make technological advances. In practice however, a clear-cut distinction between scientist and engineer is often impossible. Scientists frequently seek out practical applications of their new-found knowledge of nature's behavior. Engineers frequently find that they must search for still undiscovered patterns in nature before they can find a satisfactory solution to a technological problem. Because of this diffuse boundary between science and technological application, a flow of both men and ideas between the two areas is expected and encouraged.
>
> Since technology builds upon the laws of nature discovered by scientists, the capable engineer must be knowledgeable of nature's laws. In particular, because technological advance is usually the result of ingenious and insightful application of a known law, the successful engineer is usually one who possesses a wide and thorough knowledge of science. And, since the interchange must be two ways, the discoveries of a scientist are best utilized if the scientist has an understanding of the technology to which the discovery can be applied. Even though there is merit in "science for science's sake," the practical difficulties of funding the expensive difficulties of today necessitates a balance between "pure" and "applied" science (p. 1).

Despite the rhetoric about diffuse boundaries, two-way flow and pure/applied balance, the second paragraph implies that Bueche regards technology essentially as applied science. This is borne out by the treatment of specific topics in the body of the text. For example, the section on electric generators opens with the statement that "Electric generators and motors make use of coils which rotate in a magnetic field. As the coil rotates, the flux through it changes..." (p. 486) and proceeds immediately to derive the formula for induced **emf**. This is pure physicists' physics, no different from the treatment in any other standard physics text. There is no mention of the engineering in this, that it took years of work to settle basic design issues about the shape of the magnet and the best way to wind the wires around the coil. It totally ignores the question of how a scientific idea is turned through engineering into a useful artefact. Various writers (Mayr, 1971; Layton, 1971; Kline, 1987) have noted how 19th century electrical engineers had to go beyond the boundaries of abstract physics (Maxwell's electromagnetic theory) and develop an engineering theory of the motor (or dynamo) in order to make progress. For example, John Hopkinson, an English engineer working in co-operation with Thomas Edison, devised a graphical method of describing d.c. dynamo behaviour. The significant improvements which resulted could not be deduced from Maxwell's theory. The prologue to Bueche's play tells us how important engineering is, but the character never actually appears.

PSSC Physics
In secondary school texts, the "pure physics" story-line can be found in such well-known texts as PSSC Physics (Haber-Schaim, Dodge & Walter, 1986). This edition does, however, make some minor concessions to technology. For example, the introductory chapter on kinematics contains a "Sideline" which describes a rocket-propelled car designed to break the sound-barrier. This material is presumably introduced to help make the chapter more interesting; however, the content is never mentioned again. At various places, technological applications are introduced: for example, the chapter on electric circuits begins with a photograph of a bank of batteries in an electric car. The section on meters and motors resembles Bueche's, although there is an acknowledgement that the use of electromagnetic force

> is very widespread and a great deal of understanding and skill have been employed in inventing, designing and building all the devices in which it is used. This is the work of electrical engineers, who have for about a century carried the applications of this force to new uses. We are not going to try to describe the ingenious and often complex ways they have found to use the force; that is another subject (p. 307).

Thus, as with the characters of Rosenkranz and Guldenstern in Shakespeare's Hamlet, we must await the arrival of another playwright to develop their story more fully.

Kane and Sternheim (1978)
This introductory college physics text has been written with life science students in mind. The text explicitly recognises the role of instrumentation:

> Perhaps the most obvious impact of physics on biology and medicine is at the level of instrumentation. A knowledge of physics helps in the intelligent use of everything from light microscopes and centrifuges to electron microscopes and elaborate radiation detection systems used in nuclear medicine (p. xii).

The book contains numerous examples consistent with this view: holographic photography for studying biological specimens, medical applications of fibre optics, magnetic studies of the human body to detect asbestos, centrifuges for separating particles in biological research, electro-encephalographs for diagnosing brain disorders, and so on. These artefacts are presented simply as existing devices which are of practical use to professionals in biological fields and whose workings can be understood in terms of physics. There is no discussion of how these artefacts evolved, or of the ways in which instrumentation has re-shaped our views about what constitutes biological knowledge.

Giancoli (1984)
An undergraduate physics text by Giancoli (1984) makes no specific claims in its preface about the relationship between physics and technology but does in fact include discussions of physics and technology in many places. The author frequently takes an existing instrument, machine or engineering application, and then draws upon physics principles to explain how it "works". Hydraulic brakes are explained in terms of Pascal's Principle; Bernoulli's principle is used to account for the ability of sailing boats to move against the wind. Chapter 11, on statics ("Equilibrium, elasticity and fracture"), supplements the usual physics concepts with discussions of engineering applications, e.g. an explanation of why iron rods in reinforced concrete are subjected to tension until the concrete has dried. Discussions of numerous technological applications of physics (e.g. medical and communications applications of fibre optics, microphones, tape-recorders, nuclear reactors) are woven into the text.

Occasionally, the text presents an historical treatment showing how an important technological artefact developed from scientific research. The chapter on electric current begins with an account of Volta's methodical re-examination of Galvani's famous observations on the contractions that occurred when a frog muscle was connected to a circuit containing dissimilar metals. Galvani thought that this was due to "animal electricity". Volta demonstrated that the effect was due to the generation of electricity by the pair of dissimilar metals. This led him to invent a pile of alternate zinc and silver discs, separated by cloth soaked in salt solution, the first battery.

Other parts of the text contain information relevant to an understanding of the chronology of science-technology relationships. For example, a chapter on optics notes that "The development of optical devices using lenses dates to the sixteenth and seventeenth centuries, although the earliest record of eyeglasses dates from the late thirteenth century" (p. 670). A footnote to the section on telescopes (p. 679) comments that Galileo improved, but did not invent, the telescope, and mentions both the date of the first Dutch telescope (1604) and the date associated with an earlier Italian one (1590). These optical instruments pre-date the formulation of Snell's law of refraction, around 1621. We can contrast this treatment with that of Bueche and of Serway and Faughn. One chapter in Bueche takes the reader through reflection, plane mirrors, ray diagrams, refraction (including Snell's Law) and thin lenses; a later chapter deals with magnifying glasses, simple telescopes and compound microscopes. Although an eminently *logical* sequence (the earlier chapter contains scientific ideas which explain how the artefacts "work"), this is physics torn from its historical setting, a physics story which misrepresents the technology story. No mention is made of the historical precedence of the technology over the science. Serway and Faughn adopt a similar story-line. Readers of these texts may be forgiven for believing that the technological outcomes resulted from scientists' knowledge about light rays and the laws of refraction.

In common with most undergraduate science texts, Giancoli has little to say about the process of technological design (in the sense of conceiving, inventing, making and improving an artefact). In one section (27-6), the text discusses the design of ammeters, voltmeters and ohmmeters:

> Suppose we wanted to design a meter to read 1.0 A at full scale... (p.527)

In this context, 'design' refers to the process of taking an existing artefact (a galvanometer) and connecting other artefacts (resistors) to it appropriately in order to construct a system. A separate later section (28-11) describes the design of the galvanometer:

> The basic component of most meters, including ammeters, voltmeters and ohmmeters, is a *galvanometer*. We have already seen how these meters are designed...and now we can examine how the crucial element, a galvanometer, itself works. (p. 553)

This paragraph is accompanied by diagrams showing the inner workings of the galvanometer. The physics of the apparatus is then developed, and the reason for using semi-circular magnetic pole pieces and for mounting the coil on a cylindrical iron core is explained. This discussion of the "anatomy and physiology" of the galvanometer is consistent with the style of presentation generally used throughout the text. The design *process* — the way in which the galvanometer was conceived, invented, made and improved — is not mentioned. Occasionally, this aspect of science-technology relationships is woven into the plot (e.g. the description of the invention of the Voltaic pile), but such examples are rare.

Harvard Project Physics

The Harvard Project Physics course was developed for use in secondary schools in the 1960s. It was one of the few science curricula which made a serious attempt to introduce students to aspects of the history of science; however, it fails to recognise the role of technology and its treatment of the history of science reflects the dominant idealist view. In its account of the history of astronomy (The Project Physics Course, 1970), the central players are the ancient Greeks and the Renaissance Europeans, as if nothing of importance happened in between. The text refers to instruments designed by scientists e.g. Tycho Brahe's large wooden sighting device which improved the accuracy of measuring celestial positions. Copernicus' calculation of the period of Jupiter, expressed in years, days, hours, minutes and seconds, is described, but the fact that this scientific achievement rested on the technological creativity of the 13th century Benedictine monks who developed the mechanical clock to regulate their daily devotions is overlooked. Kepler's belief that the universe was driven by a gigantic mechanism is dealt with in a single line; this powerful mental image could not have been conceived without the mechanical inventions of the medieval technologists. Galileo's telescope is mentioned; the medieval optical technology that made it possible is not. The PSSC text (Haber-Schaim et al., 1986), in its section on the history of astronomy, follows a similar storyline, with even fewer references to technology.

Oxtoby and Nachtrieb (1990)

A recent college chemistry text (Oxtoby & Nachtrieb, 1990) explicitly recognises the ancient technological roots of modern chemical theory and practice. The chemistry of copper (pp. 703-706) is introduced with some speculation about how an early potter might have obtained the metal by firing some ore in a kiln. This is followed by a discussion of the use of copper/arsenic alloy 5000 years ago to make axes, the invention of copper/tin alloy (which gave the Bronze Age its name), and the use of brass (copper/zinc) by the ancient Romans. Similarly, the section on the chemistry of iron (p. 706) acknowledges the extraction of the metal by the Hittites in the Middle East 3000 years ago, the improvement of the process in Greco-Roman times, and the development of the blast furnace in the 14th and 15th centuries.

McMurry (1990)

This introductory organic chemistry text is clearly written, profusely illustrated (including computer-generated "three-dimensional" diagrams of molecular structures), and employs innovative ways of presenting reaction mechanisms (vertically down the page, with text alongside each step in the reaction). After a chapter on structure and bonding, nearly all the remaining chapters discuss the properties of various organic functional groups. The very first paragraph indicates the link between organic chemistry and technology: "the wood, paper, plastics and fibers that make modern life possible are organic compounds" (p. 1). The next page notes that

> Modern chemists have become highly sophisticated in their ability to synthesize new organic compounds in the laboratory. Medicines, dyes, polymers, plastics, pesticides, and a host of other substances — all are prepared in the laboratory, and all are organic chemicals (p. 2).

The core material of the text is interspersed with a set of brief "interludes", each a page or two, frequently dealing with various aspects of technology: industrial applications, history, environmental concerns. The first interlude deals with the refining of petroleum for making automobile fuel, oil, kerosene and asphalt. Another, "Natural Rubber", describes the technology of collecting, washing, drying, coagulating and vulcanizing of rubber, and notes that mechanism of the vulcanization process (heating crude coagulate with sulphur) is "still not fully understood" (p. 117). The unstated — and correct — message is that technological advances can be made without complete scientific understanding. "Alkyl halides and the Ozone Hole", discusses the environmental effects of using chlorofluorocarbons in aerosol spray cans. "Organic Dyes and the Chemical Industry" gives a brief account of the invention of the first synthetic dye, Perkin's mauve, in 1856. (The anecdote provides a nice example of how technological advances can be made through serendipity. Although Perkin was investigating the reaction of aniline with potassium dichromate, the brilliant purple dye was actually formed from an impurity in the aniline.) "Industrial Uses of Simple Alcohols and Phenols" describes the catalytic reduction of carbon monoxide with hydrogen to yield methanol on an industrial scale, and the catalysed hydration of ethylene to form ethanol.

Chapter 13 ("Structure Determination") breaks the sequence of chapters on functional groups with an extended discussion of infra-red, ultra-violet and nuclear magnetic resonance spectroscopy. The chapter opens with an acknowledgement that "extraordinary advances have been made in chemical instrumentation", presents a little physics and then discusses the interpretation of the spectra produced by the various instruments.

Although the text is clearly of high quality, some critical reactions (some minor, some more substantial) can be offered. The introductory comments about the link between the modern laboratory and chemical technology are of course true; missing, however, is any acknowledgement that medicines, dyes and fibres have been made for a few thousand years, albeit much less successfully, prior to the advent of modern laboratories, and that even today, some medicines and pesticides are developed by utilising as a starting point the technological know-how of some indigenous Third-World tribes.

The chapter on spectroscopy is open to more substantial criticism. Spectroscopy is a classic illustration of a field which Ihde (1979, pp. 35-36) describes as requiring the *mediated mediation of hermeneutics*. In contrast to instruments such as the dentist's probe or the microscope ("directly mediated embodiments", to use Ihde's phrase) which keep the observer in close proximity to the object of interest, the infra-red spectrometer generates data on phenomena not directly available to the senses. The instrument's output (the peaks and troughs on a printout) has to be 'read' and interpreted by someone 'literate' in the 'language'. A limitation of the McMurry text is that it goes straight from instrumental output to scientific knowledge; the technological underpinnings are missing. Some texts treat instruments as "black boxes"; in this text the box is literally invisible: the text contains no photograph, not even a line diagram, showing what any of the machines look like or how they work, let alone any discussion of how they were conceived, made and improved. There is no discussion of what capabilities a spectroscopist must actually have in order to prepare a specimen, mount it in a machine, operate the machine, and interpret the output.

One might reasonably respond that undergraduate texts are already very large and contain more information than can be adequately covered in an introductory semester or year. True: the point of this discussion is not to criticise a good text for what it omits, but to indicate how such a story-line can help to shape a particular view of the relationship between science and the technological instrumentation upon which that knowledge rests. Although the text explicitly acknowledges the importance of the technology, its treatment indicates implicitly that the technological details are not crucial for learners of organic chemistry: what matters is the resulting scientific knowledge. A precisely parallel argument can be mounted about the text's presentation of industrial processes such as petroleum refining and alcohol production. The brief discussion centres on the chemical reactions, without any reference to the chemical engineering which is necessary for turning a laboratory reaction into an efficient, large-scale and economic operation.

Salters and PLON

Several curriculum projects have attempted to integrate science and technology and bring technology forward to centre stage. The Salters' projects in Chemistry and in Science exemplify this approach. Ramsden (1992) describes several of the underlying principles; one is that the instructional units are *applications-led*, so that "the motivation to cope with the demands of scientific theory arises out of the fact that the theory is introduced when the 'need to know' is evident" (p. 14). Thus, in one typical unit (*Seeing Inside the Body*), students are introduced to a range of medical diagnostic techniques, including X-rays, and this is the starting point for a study of radio-activity and various forms of radiation. The technology here becomes the focus of study, the twin emphases being scientific understanding of the technology, and understanding of the uses of the technology. A similar approach is adopted by the authors of a PLON-Vereniging physics text in the Netherlands (Kortland et al., 1990); in one chapter, *Verkeersveiligheid* ("Traffic safety"), motor-cars, road surfaces, safety belts and head rests provide the technological context in which scientific concepts of force, acceleration, momentum etc. are introduced.

Although these illustrations clearly give a more central role to technology, they are still essentially *science* courses. Little attention is given to the way the *technology* was designed, made and evaluated; the courses are not centrally concerned with the development of technological capability. In the Dutch material, a safety belt is treated simply as an artefact which provides a force, spread out over time, in order to reduce deceleration in a collision. *Technological* questions — What material should be used for the webbing? Where and how should the belt be attached to the car? What is a good design for a buckle? — are not considered. To the response that these are highly specific questions, not general principles like Newton's Second Law, there is a counter-reply: precisely, this exemplifies one of the ways in which technology differs from science.

A concluding note

It will be seen that there are wide discrepancies between the way in which science-technology relations are presented in these science texts and the four criteria listed earlier. Texts which acknowledge the historical priority of technology are rare. Ontological discussions are even rarer; the importance of instruments and tools may be recognised, but they are treated either as black boxes or as illustrations of scientific principles, not as shapers of scientific thought. Scientific knowledge is highlighted; technological capability is down-played. The close two-way interaction between modern technologists and scientists in designing and making "high-tech" artefacts is rarely discussed. All the texts cited make frequent references to technology: their authors obviously recognise the importance and relevance of technology in science education. However, the richness and complexity of science/technology relationships is seldom portrayed adequately. The central purpose of the present article is to invite educators (the writers of science texts and the university and school teachers who use them) to consider devising story-lines which more accurately reflects the nature of the relationships between these two great domains of human enterprise.

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THE HISTORICAL CONTEXT OF NEWTON'S THIRD LAW AND THE TEACHING OF MECHANICS

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ABSTRACT

Many studies have shown that Newton's Third Law of Motion is not easy for students to accept when they consider the interaction of two objects. A number of prominent science educators believe that it should not be taught to students before Year 11. This paper reports the results of a study of the historical origins of Newton's Third Law with a view to identifying the context from which it emerged in the 17th century and the conceptual changes which accompanied its emergence. Some of the possible implications of a study such as this for improving the teaching of introductory mechanics are discussed.

INTRODUCTION

In 1893 Mach claimed that "perhaps the most important achievement of Newton with respect to the principles [of mechanics] is the distinct and general formulation of the law of the equality of action and reaction, of pressure and counter-pressure" (Mach, 1960, p. 243; Mach's emphasis). It is not possible to understand properly the behaviour of real, everyday objects consisting of a number of interacting parts without a correct concept of Newton's third law (Gauld, 1992) and such a principle cannot simply be left for the more detailed, mathematical treatment of mechanics in the senior high school physics course undertaken by only a relatively small number of students. However, studies of student conceptions of the forces between interacting bodies (see, for example, Brown, 1989; Maloney, 1984) have demonstrated that these rarely coincide with the physicist's (or Newton's) understanding of the relationship between these forces. This paper deals with the historical background to Newton's own statement of the third law of motion with a view to identifying aspects of this development which could assist the teaching of the law to modern day students.

THE THIRD LAW IN NEWTON'S PRINCIPIA

In the English translation of the third edition of the Principia (Newton, 1729) Newton's own statement of the third of his three laws of motion reads "To every action there is always opposed an equal reaction; or the mutual actions of the two bodies upon each other are always equal, and directed to contrary parts" (p. 23). Newton's examples, immediately following this statement, include the forces of a finger on a stone and the stone on the finger, the forces between a horse and a stone (both of which are connected by a rope), the forces between two colliding bodies, and 'attractions' between objects - that is, forces, such as gravity, which act at a distance rather than through direct contact (pp. 23-24).

In the Scholium which concludes this introductory section of the Principia (and precedes Book I) Newton provided some indication of other work which, he claimed, supported the general principles summarised in his three laws of motion and the six corollaries derived from them. In relation to his third law he referred to the investigations, using pendulums, into "the rules of the congress and reflexion of hard bodies" carried out by Wren, Wallis, Huygens and Mariotte

(p. 30) and he went on to describe his own experiments using tightly compressed balls of wool and balls of steel, cork and glass. He concluded "thus the third Law, so far as it regards percussions and reflexions, is proved by a theory exactly agreeing with experience" (p. 32).

Of those mentioned by Newton in this context the first to arrive at a general understanding of the nature of collisions was Christiaan Huygens who produced a comprehensive solution for what we now call elastic collisions in 1656 although the details were not published until 1703 after his death (Gabbey, 1980). Huygens was strongly influenced by Descartes' Principles of Philosophy (Descartes, 1644) as were many others during the 17th century. Newton, while explicitly critical of some of Descartes' views (Koyré, 1965), was also influenced more positively by other aspects of Descartes' thought (Herivel, 1965, pp. 42-53). Huygens demonstrated the power of his analysis of elastic collisions to a group of people (including Wren and Wallis) during a visit to London in 1661 (Hall, 1966; Yokoyama, 1972) and summaries of the results of Wren, Wallis and Huygens were published in 1669 in the Philosophical Transactions of the Royal Society.

ANALYSIS OF COLLISIONS IN THE 17TH CENTURY

Throughout the 17th and into the 18th centuries collisions between bodies was the paradigm for modelling the transmission of influences in many different phenomena such as gravity, magnetism and light and Newton's laws of motion were developed in the context of impact phenomena (Arons & Bork, 1964; Gauld, 1975). Descartes championed the notion of a mechanical universe and attempted to develop a theory of mechanics from fundamental, universally accepted principles. He began with the presupposition that God had created the universe and that He preserved the quantity of matter and the quantity of motion within it (Descartes, 1644, p. 215; see also Blackwell, 1966). From this presupposition a number of principles followed.

(a) A body far removed from other objects remains at rest or continues with a constant speed in a straight line.

(b) When a moving body collides with another which has a greater resistance to change the first will change its direction but preserve its 'motion' [our mv].

(c) When a moving body collides with another which has a smaller resistance to change both bodies move together with the first losing 'motion' and the second gaining an equal amount (Descartes, 1644, pp. 217, 218).

For Descartes the direction in which an object moved was not involved in his concept of 'motion' which was thus treated as a scalar quantity instead of as a vector and so differed from our modern 'momentum'. For Descartes the results of collisions were brought about not by the operation of forces but, in (b) above, by the nature of hard bodies and, in (c) above, by God's maintenance of a constant quantity of motion as some passed from one body to another (pp. 218, 219).

Descartes claimed that it was easy to calculate the outcome when two perfectly solid, isolated bodies collided even though he did not carry through the calculation. However, he admitted that "in our environment we do not ordinarily get perfectly solid bodies; so it is much harder to calculate how the motions of bodies are changed by collisions with others" (p. 220).

Even an ardent supporter of Descartes such as Huygens soon realised that, for the ideal situation that he considered, Descartes' conclusions about perfectly hard, colliding bodies could not be correct. Huygens used an elegant procedure based on the notion that colliding bodies should obey the same laws of impact whether viewed by a stationary observer or by one moving with a constant velocity (Dijksterhuis, 1961, pp. 373-376). For example, two bodies colliding head-on with equal speeds could be transformed into a collision in which one was at rest by an observer who moved along with one of the bodies. From this perspective the moving body now had a speed twice as large as it had for an observer at rest. For Huygens these two collision were equivalent.

If a large body was at rest and a small, moving body collided head-on with it Descartes had predicted that the smaller body would bounce back with the same speed, v. An observer travelling along with it at a speed v as it approached the collision would see the larger body approaching with a speed v towards the smaller body at rest. After the collision this observer would see the larger body continue on with unchanged speed and the smaller one move off in the same direction as the larger one with a speed of 2v. In this case motion would have been created contrary to Descartes' original presupposition. This conclusion also contradicted Descartes' second prediction (see (c) above) for the approach of a large body where he expected both to move off together.

It was well known during the middle of the 17th century that if two 'hard' bodies approached each other with the same 'motion' (i.e. with speeds inversely proportional to their masses) they would rebound with their directions reversed but their speeds unchanged. In 1656 Huygens' device enabled him to transform collisions between bodies with any masses and speeds into this situation and so provided a general solution for collisions between hard bodies. In this way he demonstrated that, in such a general collision, the relative velocity between the two bodies maintained the same size but reversed its direction. He also showed that, while the scalar sum of mv could change (in contradiction to Descartes' presupposition) the sum of mv^2 was constant.

However in all of this quite sophisticated analysis Huygens refrained from using the concept of force and worked solely from kinematical rather than from dynamical premises (Westfall, 1971, pp. 151-152).

Both Wren (1669) and Wallis (1669) - the first dealing with what we now call perfectly elastic collisions, the second with perfectly inelastic collisions - based their analyses on an analogy with the balance or the lever which dominated much of the study of force and motion in the 17th century (Hall, 1966). For Wren, balance existed when the speeds of approach were in inverse proportion to the masses of the bodies since, in this case, the bodies bounced back with unchanged speeds (Hall, 1966). As much as the incoming speeds depart, in one direction, from this condition so they must be compensated for by an equal amount afterwards in the opposite direction. This led him to a correct analysis of all types of elastic collision. Although the conception was different to that of Huygens, Wren's solution was immediately recognised as structurally equivalent to Huygens' (Hall, 1966).

In his analysis of collisions in which the colliding objects stuck together Wallis adopted an impetus concept of force - force = weight x celerity (or speed) - in which the final force of the combined bodies, $(W_1 + W_2)C$, was equal to $(W_1C_1 + W_2C_2)$ if the objects were travelling in the same direction when they collided or $(W_1C_1 - W_2C_2)$ if they were approaching each other (Wallis, 1669; Hall, 1966).

Mariotte published his studies of impact in 1673 and in them adopted a concept of the 'force of a body's motion' which was effectively the medieval concept of impetus. Mariotte also used the analogy of equilibrium for inelastic bodies so that two approaching bodies with speeds inversely proportional to their masses (and so with equal 'forces') would stop on impact. If these 'forces' were not equal, motion would occur in the direction of the larger 'force' as in Wallis' analysis. To understand elastic collisions Mariotte invoked the elasticity of the bodies. Two approaching elastic balls with speeds inversely proportional to their masses would, during the collision, come to rest with the balls distorted and stressed. In returning to their original shapes the balls would rebound at their original speeds. Using a procedure like that of Huygens or Wren, Mariotte showed that all collisions could be reduced to a collision like that above by subtracting or adding the velocity both bodies had in common, that is, by relating collisions to the common centre of mass of the two objects (Westfall, 1971, pp. 243-249).

Following the publication of the first edition of Newton's Principia in 1687, Huygens' analysis of the laws of elastic impact was refined by Leibniz in 1692 (Westfall, 1971, pp. 291-292) and summarised in three principles which we express today as

$$u_1 - u_2 = v_2 - v_1$$

$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$$

$$m_1u_1^2 + m_2u_2^2 = m_1v_1^2 + m_2v_2^2$$

The first and the third of these were also enunciated by Huygens. The second is the law of conservation of momentum in its vector form.

NEWTON'S TREATMENT OF THE THIRD LAW BEFORE 1687

The first edition of the Principia was published in 1687 when Newton was 45 years old but the direction of thought which it consolidated and clarified was established when he first began to think systematically about mechanics sometime between 1664 and 1666 in his early twenties. His earliest recorded investigation of the interaction of two bodies was the section headed "Of Reflections" dated by Newton "Jan. 20th 1664" in what he called the "Waste Book" (Herivel, 1965, pp. 132-135). The behaviour of bodies which stuck together after collision (that is, bodies which according to Newton "have noe vis elastica [elastic force]") was discussed with reference to the principle of conservation of 'motion'. Because the total 'motion' of both bodies was unchanged after the collision of two approaching bodies the excess of 'motion' (i.e. the total 'motion' treated as a vector) was shared between both bodies according to their 'bulke' (or mass).

Within this same period Newton presented, in a list of "Axiomes and Propositions", statements which represent early versions of his third law. For example Propositions 7 and 8 read:

7. If two bodies [a and b moving ?] against one another the same way towards O, (a) overtaking (b) none of their motion shall be lost, for (a) presses [(b) as much] as (b) presses (a) and therefore the motion of (b) shall increase [as much] as that of (a) decreaseth.

8. If two quantities (a and b) move towards each other and meet in O, Then the difference of their motion shall not bee lost nor loose its determination [direction]. For at their occursion they presse equally uppon one another and therefore one must loose noe more motion than the other doth; soe that the difference of their motions cannot bee destroyed (Herivel, 1965, p. 142; Herivel's reconstruction of the text in square brackets).

In Proposition 9 Newton claimed that, for two "equall and equally swift" bodies which rebound after collision with the same speed they had before the collision, the balls would be distorted so that elastic forces between the balls would put a stop to their movements. As the shape of the balls was restored the balls would gain as much speed as they lost but with their directions reversed (p. 142).

At the beginning of Proposition 108 in the "Waste Book", Newton stated an assumption which, presumably, he expected to be acceptable to everyone: "Tis knowne by the light of nature that equall forces shall affect an equall change in equall bodies" (p. 157). Even at this early stage in Newton's thought he seemed, in Propositions 119 to 122, to take the same attitude towards what was to become his Third Law of Motion (see especially Proposition 119).

121. If 2 bodys p and r meet the one the other, the resistance in both is the same for soe much as p presseth upon r so much r presseth upon p. And therefore they must both suffer an equall mutation in their motion.

119. If r presse p towards w, then p presseth r towards v. Tis evident without explication.

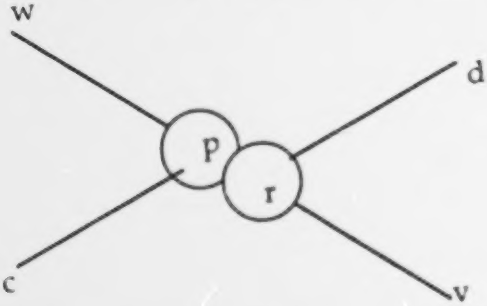

Fig. 1 Two-body collision from Newton's *Waste Book* (adapted from Herivel, 1965, p. 159)

120. A body must move that way which it is pressed.

122. Therefore if the body p come from c and the body r come from d soe much that p's motion is changed towards w, so much the motion of r will be changed towards v. vide prop. [?] (Herivel, 1965, p. 159; Newton's order).

Following his discussion of the effects of forces acting on different bodies Newton dealt with the movement of the centre of mass of two non-colliding objects and showed that this is along a straight line with a constant speed. General collisions between two balls travelling along paths which were not collinear were then treated using the principle that the motion of the centre of mass was not affected by the collision (pp. 161-170).

Eventually, in his manuscript on the "Laws of Motion" (written before 1669) he discussed the collision of nonspherical objects (pp. 208-213).

After breaking his investigation of mechanical principles for 15 years between 1669 and 1684 Newton took up the study again in the tract "De motu". In the third version of this tract he made a sharp distinction between innate force "by reason of which [a body] endeavours to persist in its motion along a straight line" and the impressed force which brings about a "change in the state of movement or rest [of a body]" (Herivel, 1965, p. 299).

At about the same time Newton produced drafts of six laws of motion in which Law 3 reads:

> As much as any body acts on another so much does it experience in reaction. Whatever presses or pulls another thing by this equally is pressed or pulled ... If a body impinging on another changes by its force the motion of the other then its own motion (by reason of the equality of the mutual pressure) will be changed by the same amount by the force of the other. If a magnet attracts iron it is itself equally attracted, and likewise in other cases (Herivel, 1965, p. 313).

Newton's early writings demonstrate how well developed was his notion of force as something which produced change in 'motion' (or momentum) and was measured by the size of this change. This is to be contrasted with the more prevalent view of his time, namely, that force brought about a change of position and was measured by the size of the 'motion' (mv) rather than the magnitude of its change. Even at such an early stage in his career Newton's analysis of collisions strikes one as more sophisticated and general than those of Huygens, Wren or Wallis. It provided a comprehensive treatment of two-dimensional as well as of one-dimensional collisions which speaks clearly of Newton's genius and of the clarity of his concept and its implications. The only significant (though not widespread) precursor to his third law was the concept expressed by both Borelli and Wallis (Westfall, 1971, pp. 225, 241) that the forces of the blows on each of two colliding bodies were equal and opposite but with a magnitude equal to the sum of the 'forces' of each body before the collision.

The Principia does represent a development of his early position but it also displays remnants of other views. For example, in Definition III, Newton's concept of "vis insita, or innate force of matter" (Newton, 1729, p. 13) appears to be related to the notion of 'impetus' (the force of motion) which was derived from medieval physics although he also called it "vis inertiae" which relates to its property of resisting change (pp. 13, 14). In Newton's definitions it is contrasted with the "vis impressae" (impressed force) of Definition IV (p. 14).

However, the 'innate force of matter' seems to have been distinguished in Newton's mind from 'impetus'. Impetus was the force which a body possessed as a result of its mass and its velocity and through which it could act on other bodies. On the other hand 'vis insita' was the force by which a body resisted change caused by outside influences. It acted on other bodies only in the course of preventing change to itself by those other bodies. As Newton wrote "it is impulse, in so far as the body, by not easily giving way to the impressed force of another, endeavours to change the state of that other" (p. 14).

Even in Newton's third law his conception of 'action' (and 'reaction') is not totally consistent with our present understanding of these notions (see Home, 1968). In the Scholium in which he discussed evidence for his three laws, one example which, he claimed, supported the third law was that of simple machines such as the lever, pulley, screw, and wedge (Newton, 1729, pp. 33, 34). Action here was associated with the product of the applied effort of the hand and its speed while reaction related to the product of the load and its speed.

IMPLICATIONS FOR TEACHING MECHANICS

If one is concerned to use history to contribute to the teaching of mechanics rather than for teaching about the cultural context of mechanics four approaches can be identified.

- The topic can be taught by following the historical sequence closely and including the quantitative aspects as well as the qualitative ones.

- One can teach the topic following the historical sequence but omit the quantitative aspects on the grounds that they often cause problems for learners.
- The conceptual development of the topic can be taught without reference to idiosyncratic elements related to the people involved.
- History can be used as a pool of potentially useful ideas which can be adapted for use by teachers without any explicit reference to their historical context.

If one adopts the last of these approaches the characteristics of present day learners need to be taken into account before deciding on the use which can be made of the historical setting in which the third law developed.

For scientists in the 17th century the laws of motion were closely related to experiments in which hard or soft bodies collided and pendulum experiments still offer a number of advantages in discussing these laws with students today.

- Forces on different objects can be compared without reference to time (or, for equal masses, without reference to either mass or time).
- The effect of gravity is cancelled by the effect of the supporting string so vertical forces can be ignored.
- External resistances are reduced to a minimum.
- The distance travelled by a pendulum bob to and from its lowest point is a good measure of its speed at that point (a fact well known to Huygens, Wren, Wallis and Newton; see Newton, 1729, p. 30).
- Newton's third law can be introduced in a dynamic rather than a static context in which it is so often misunderstood.

The most significant change which took place in 17th century mechanics was a modification in the concept of force which determined how collisions were understood. A lengthy interview which was conducted with two 4th year University students, who had completed first year physics three years before, helped to clarify their understanding of what was happening in such collisions. They observed a number of collisions between two steel pendulum bobs and it became obvious that the concept of force which they possessed was very similar to the impetus notion so often found among younger students. In an inelastic collision with one stationary bob where the two bobs stuck together they believed this force was conserved and resulted in a smaller speed after the collision because the mass was now larger. Two balls colliding with different speeds and sticking together moved off in the direction of the larger force and with a speed determined by the difference between the original forces. For an elastic collision between bobs of equal mass (with one initially at rest) the force of the first was transferred to the second which moved off with the same speed as the incoming one; the incoming bob experienced a force equal and opposite to its original force and so it stopped dead. Two identical bodies, colliding elastically with equal speeds, transferred their forces to each other and bounced back. For these students the most puzzling event occurred when a large, moving bob collided elastically with a small, stationary one and continued on after the collision (although with reduced speed). They argued that, according to their understanding of Newton's third law, the incoming bob should stop since the reaction force from the stationary ball was equal to the force of the moving ball.

Thus the context of collisions is one in which the implications of alternative conceptions of force can be discussed and a change in student concepts encouraged. In a teaching approach based on pendulum collisions students could explore, with or without assistance from the teacher, some of the consequences of the "newtonian" understanding of force and contrast it with their own. A distinction could even be drawn between the 'internal' force of a moving body (to which Newton's third law does not apply but which many students probably adopt) and the 'external' force on a body (to which Newton's third law does apply).

Some features which were crucial in the historical development may not be so appropriate in teaching mechanics. For example, the analogy between the lever and collisions which was such a powerful influence during the 17th century may not be so fruitful for modern students. They may find other images more appealing.

Newton's demonstration of the value of his notion of force as something which produced change in 'motion' was based to a large extent on the quantitative analyses of Huygens, Wren and Wallis as well as on his own detailed explorations in the "Waste Book". For some modern students, dealing with the mathematical aspects of collisions could hinder understanding rather than promote it and a qualitative treatment may be more effective in teaching. For others, a treatment using simple ratios for the masses and the speeds of the colliding objects can be substituted for the fuller historical analyses.

Even if one wished to relate the pedagogical development more firmly to the historical context the above considerations would still have to be taken into account in deciding just how this should be done.

CONCLUSION

The similarity between the ideas of force held by modern students and pre-Newtonian scientists indicates that a study of the conceptual change to a Newtonian view of mechanics which took place in the 17th century could be a fruitful source of ideas for teaching mechanics. The emphasis at that time on impact as the context in which the Newtonian concept of force emerged suggests that this may have some advantages when teaching a dynamic-interactionist notion of force in which Newton's third law takes on central importance.

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EFFECT OF CONTEXT AND GENDER ON APPLICATION OF SCIENCE INVESTIGATION SKILLS

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ABSTRACT

Two parallel versions of a Test of Science Investigation Skills were developed to assess students' application of science investigation skills in biology and physics contexts. Repeated pilot testing and critical appraisal were used to ensure the validity of the tests and their equivalence. Both versions of the test were administered to 112 Year 10 science students. The results indicated a satisfactory level of test reliability, the test set in a physics context proved to be significantly more difficult than the test set in a biology context, and mean scores for male and female students were not significantly different.

INTRODUCTION

Considerable interest has been shown in science investigations in the secondary school curriculum in the past five years. National curriculum statements in the UK, New Zealand and Australia have listed science investigation skills as important learning outcomes. In the UK (Department of Education and Science, 1983) and Canada (Erickson, Bartley, Carlisle, Meyer & Stavy, 1992) large scale testing of these skills has been conducted to assess levels of skill attainment.

In Western Australia Hackling and Garnett (1991, 1992) have studied Year 7, 10 and 12 school students, third year university students, and expert research scientists as they work on a practical, laboratory-based investigation of the factors that influence the bending of beams under load. These studies revealed that the students had limited skills of problem analysis, planning and conducting controlled experiments, basing conclusions only on obtained data, and recognising methodological limitations of their investigations. These studies involved working with individual subjects who produced think-aloud protocols and recording their manipulations of apparatus on video tape. As a consequence of the methodology chosen, the studies were limited to small sample sizes and to a single investigation set in a physics context. This study used a pencil and paper test methodology that would allow testing of larger sample sizes and the assessment of students' abilities to apply science investigation skills in different contexts.

The purposes of this study were to: (a) develop a pencil and paper test of science investigation skills and assess the reliability of the instrument; (b) use the instrument to assess Year 10 science students' attainment of science investigation skills and knowledge; (c) compare the performance of students on versions of the test set in physics and biology contexts; and (d) compare the performance of male and female students on the test.

METHOD

Instruments

Two parallel versions of the Test of Science Investigation Skills (TOSIS) were developed. One version was set in a physics context and was closely patterned on the bending beams task used in the practical tests conducted previously (Hackling & Garnett, 1991). The second version was set in a biology context and involved an investigation of factors influencing the growth of cucumbers. The test comprised five open-ended questions related to the biology or physics context and a set of seven multiple choice questions which was common to both tests. Repeated pilot testing and critical appraisal were used to ensure the validity of the tests and their equivalence.

Both versions of the test assessed students' abilities to:

- identify variables for testing in an investigation;
- identify dependent, independent and controlled variables from a description of an experiment;
- write an hypothesis;
- select an appropriate definition of hypothesis;
- plan an experiment with control over interfering variables and with an adequate sample size;
- evaluate an experiment identifying any lack of control of variables or inadequacy in sample size;
- draw appropriately tentative conclusions from experimental results;
- recognise that scientific conclusions are subject to revision;
- recognise that results ought to be accurate and repeatable; and
- select an appropriate definition for theory.

Subjects and Procedure

Both versions of the test were administered to 112 Year 10 students from five different science classes selected from four Perth schools in low, medium and high socioeconomic areas. All classes were drawn from the top half of the population in terms of science achievement. An equal number of students did the biology and physics versions of the test first. Equal numbers of male and female students participated in the study.

RESULTS AND DISCUSSION

Test Reliability

The correlation between the students' total scores for each version of the test was 0.77 which indicates a satisfactory level of test reliability.

Application of Science Investigation Skills

The performance of students on the context-specific open-ended questions and the common set of multiple choice questions is summarised in Tables 1 and 2 respectively. These data from the pencil and paper TOSIS test are compared with the results from the practical investigation test previously reported by Hackling and Garnett (1991).

Identification of variables. On the practical test (Hackling & Garnett, 1991) many students commenced the investigation by identifying variables for testing, although most potential independent variables were identified by students while experimenting. None of the Year 7, 10 or 12 students used the terms variable, independent, dependent or controlled variable while working on the practical investigation.

On the two versions of the pencil and paper test (TOSIS) students were fairly successful in generating three relevant variables for testing (37% physics, 79% biology) although context appears to influence the difficulty of the task. On the multiple choice questions students were

TABLE 1
STUDENT RESPONSES TO THE CONTEXT SPECIFIC, OPEN-ENDED QUESTIONS ON THE PHYSICS AND BIOLOGY VERSIONS OF THE TEST

Question	Skill	Percentage of students	
		Physics version	Biology version
Q1.	Identified three relevant variables for testing.	37	79
Q2.	Wrote an hypothesis as a relationship between an independent variable and the dependent variable.	40	34
Q3.	Controlled the two main interfering variables.	34	19
	Planned to conduct experiments "under the same conditions".	2	18
	Specified how the dependent variable would be measured.	25	31
	Planned for an adequate sample size.	1	9
Q4.	Recognised that the experimental design is poor and therefore conclusions must be tentative.	5	2
	Formulated an appropriate conclusion.	81	88
Q5.	Recognised that a key variable was not controlled.	55	33
	Recognised that the sample size was inadequate.	0	4

also able to distinguish between types of variables with 88%, 78% and 61% of students able to identify the independent, dependent and controlled variables respectively, from the description of an experiment. This provides an interesting contrast with students' work on the practical test where the terms relating to variables were not used. It appears from this that many Year 10 students are aware of the terminology and can identify types of variables but the terminology has not been integrated with their investigations procedural knowledge, or is simply seen as theory and is not part of the language register of laboratory work. Toh and Woolnough (1993) discuss similar language factors limiting the extent to which students' control of variables is fully reported in students' written records of investigations.

Hypothesising. On the practical test (Hackling & Garnett, 1991) only four of 30 students mentioned the word hypothesis, none formulated an hypothesis to guide their work. On the pencil and paper test less than half of the students (40% physics, 34% biology) were able to formulate an hypothesis written as a relationship between an independent variable and the dependent variable. On a multiple choice item significant numbers of students selected answers corresponding to the misconceptions that hypotheses can be proven to be true (21%) or hypotheses are theories that have been verified (14%). Further confusion about

TABLE 2
STUDENT RESPONSES TO THE MULTIPLE CHOICE QUESTIONS COMMON TO BOTH VERSIONS OF THE TEST

Question	Knowledge or skill	Percentage of students
Q6.	Identified the independent variable from a description of an experiment.	88
Q7.	Identified the dependent variable from the description of an experiment.	78
Q8.	Identified a controlled variable from a description of an experiment.	61
Q9.	Selected a definition of an hypothesis as "a tentative explanation that can be tested".	59
	Had the misconception that hypotheses "can be proven to be true".	21
	Had the misconception that an hypothesis "is a theory that has been verified by other scientists".	14
Q10.	Recognised that experimental results should be "accurate and repeatable".	71
	Had the misconception that experimental results should be "tentative and subject to change".	20
Q11.	Selected a definition of a theory as "explanations that have been supported by the results of many experiments".	41
	Had the misconception that a theory is an "hypothesis that needs further testing".	40
	Had the misconception that theories are "hypotheses that were not supported by the results of experiments".	15
Q12.	Recognised that scientific conclusions are "subject to revision".	79
	Had the misconception that scientific conclusions "are accepted by everyone".	12

hypotheses and theories were revealed on another multiple choice question where 40% of students had the misconception that a theory is an hypothesis that needs further testing, and 15% thought that theories are hypotheses that were not supported by the results of experiments. There appears to be much confusion regarding the nature of hypotheses, types of hypotheses, and the difference between hypotheses and predictions (Wenham, 1993). Clearly there is a need for more effective and explicit instruction regarding the concept of hypothesis.

Planning a controlled experiment. On the practical test none of the students verbalised an intention to control variables as they planned and conducted their experiments. The experiments they conducted exhibited poor control of variables. When asked to plan an experiment to test a given hypothesis on the written test, approximately a third of the students (36% physics, 37% biology) either explicitly controlled the two main interfering variables or stated that they would conduct their experiments "under the same conditions". There was a total of six variables that needed to be controlled in the experiments students were asked to plan. Students' plans, on average, controlled 1.34 variables on the physics version and 1.26 variables on the biology version of the test. Other noticeable features were that only a modest proportion of students (25% physics, 31% biology) specified in the plan of their experiment how they would measure the dependent variable, and a very small number of students (1% physics, 9% biology) specified an adequate sample size.

Interpreting the results from an experiment, and recognising methodological weaknesses. On the practical test half of the Year 10 students went beyond their experimental data in drawing conclusions. On the written test students were presented with information about how an experiment had been conducted and the results from the experiment. Most students (81% physics, 88% biology) were able to draw appropriate conclusions although only a few students (5% physics, 2% biology) recognised the methodological weaknesses in the experiment and that the conclusions must therefore be rather tentative.

The next question on the written test asked students to identify any aspect of the experiment that might contribute to inaccurate or misleading results or conclusions. When specifically prompted, some students (55% physics, 33% biology) were able to identify lack of control over variables but almost none of the students (0% physics, 4% biology) were able to recognise the totally inadequate sample size. In the debriefing at the end of the practical investigation students had great difficulty in identifying the methodological limitations of their work.

Effect of Context Both versions of the test had five open-ended context specific questions. These questions had a maximum possible score of 16. The mean total score for all students (N=112) on the context-specific questions in the biology version of the test was 6.31 (st dev 2.74) and 5.57 (st dev 2.74) on the physics version of the test. The physics version of the test was significantly more difficult than the biology version ($t = 3.34$, $p < .01$ for a two tailed t test for paired data).

Both versions of the test required students to work with the same number and types of variables, and to perform the same operations on the given information. Familiarity with the contexts of the tasks appears to have influenced the difficulty of the two versions of the test. The physics version based on an investigation of the effect of beam characteristics on the amount they bend under load is probably less familiar to many students than the biology version based on an investigation of factors influencing plant growth. The most noticeable differences in student performance were related to identification of variables to be tested (37% vs 79%), identification of variables to be controlled (34% vs 19%), and recognition of uncontrolled variables (55% vs 33%). It would be expected that students' familiarity with the phenomena would influence their knowledge of important variables. Domain specific knowledge and performance on these tasks are inextricably linked (Woolnough, 1991).

Effect of Gender The two versions of the TOSIS test had a maximum possible total score of 23. On the biology version of the test male students (N = 56) had a mean total score of 11.13 (st dev 3.31), female students (N = 56) had a mean total score of 11.04 (st dev 3.89). On the physics version of the test male students (N = 56) had a mean total score of 10.57 (st dev 3.27), female students (N = 56) had a mean total score of 9.86 (st dev 3.57). Males had a slightly higher mean score than females on both versions of the test. The difference between male and female scores was greatest on the physics version. None of the differences between means was statistically significant.

CONCLUSIONS

Although this paper and pencil test of the knowledge and skills associated with science investigations has limitations because of the testing mode it has provided data that complements the findings from the practical test upon which this written test was modelled. Many of the Year 10 students experienced difficulty witn the concept of hypothesis and theory, formulating hypotheses, planning experiments that control variables and utilise an adequate sample size. The results of both the practical and written tests indicate that students are likely to place far too much confidence in experimental findings because of their lack of awareness of methodological weaknesses in the experiments by which the data were generated.

The significant effect of context on test difficulty may be related to the students' familiarity with and knowledge of the phenomena investigated in the test. There was no measurable effect of gender on test performance on the pencil and paper test. This result was consistent with the findings of the practical test on which individual differences appeared to be far greater than any differences between males and females.

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"HANDS ON - MINDS ON": INTRODUCING OPENNESS INTO SENIOR BIOLOGY PRACTICAL WORK

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ABSTRACT

This paper outlines some initial findings from research on senior secondary Biology students carrying out open investigations. The study focuses on a group of 98 Form 6 (year 11) students in a large urban co-educational school. Initial findings indicate a mismatch between the students' declared confidence of their ability to plan open investigations in Biology and their demonstrated competence. Other factors germane to the introduction of problem-solving activities of an open nature into senior Biology programmes are discussed as are the implications of these for further research and classroom practice.

INTRODUCTION

Practical activities in science may be termed "open" if students are given the initiative for finding solutions to problems (Simon, Jones, Fairbrother, Watson & Black, 1992). This approach requires students to accept responsibility for making decisions regarding their practical investigation and are required to integrate knowledge and skills from a wide variety of sources and contexts. Investigations can be "open" to varying extents along three continua of definition of task, choice of method and expected outcome.

The research which generated these initial findings forms part of a collaborative action research programme involving the author and four teachers of senior biology in a large urban co-educational school. The research is focussed on practical work in senior biology, in particular at the Form 6 (Year 11) level where initial observations indicate that "recipe following" experimentation is common i.e., students follow carefully detailed teacher developed instructions. The research strategy we are following is a process of negotiated intervention as defined by Jones, Simon, Black, Fairbrother and Watson (1993).

In the early stages of 1993 I visited the classrooms to become conversant with the existing teaching learning situation and to enable the students to become used to my presence in their classroom. We administered a student survey of the students' declared confidence with aspects of carrying out of an investigation, and followed this immediately with all students writing out their individual and group designs for an investigation of a simple contextual problem. Following this the students were asked to design and carry out a complete investigation, recording their decision-making and their findings in a work book formatted for ease of analysis. I continue to visit the Biology classrooms and to discuss the progress of the project with the teachers, planning future interventions and discussing and monitoring any changes to the teaching styles of the teachers involved in the project.

This paper reports on the student survey, their planning for an investigation of the simple contextual problem and their design and performance in the complete investigation.

IN CARRYING OUT AN INVESTIGATION

Method

All 98 students in four classes completed a questionnaire designed to establish their felt (declared) confidence about various aspects of an investigation. Fourteen aspects of process of investigating were identified. The broad themes were focussing and planning, information gathering, processing and interpreting and reporting. The expected sophistication of the students with regard to their ability at carrying out an investigation was based on the statements at level 6 in the "Developing scientific skills and attitudes" learning strand in the draft New Zealand Curriculum Statement in Science, Ministry of Education, (1992). The aspects were written in language not expected to be difficult for Form 6 students and were tried out with students from another secondary school. Sample item: " I can make hypotheses (predictions)" The response made for each item was Very confident / Reasonably confident / Not very confident / Not confident at all, scored 4 / 3 / 2 / 1. The average ratings were then ranked. The results are shown in Table 1.

TABLE 1
ASPECTS OF INVESTIGATION RANKED ACCORDING TO FORM 6 BIOLOGY STUDENTS' RATING OF THEIR CONFIDENCE IN ACHIEVING THEM

ASPECTS OF INVESTIGATION	Ranking	Rating
I can take measurements using appropriate measuring devices.	1	3.51
I can present data in an appropriate form.	2	3.34
I can select appropriate equipment to carry out an experiment.	3	3.29
I can make decisions about how many times to repeat an experiment.	4 =	3.12
I can use appropriate language and layout when presenting what I have found out.	4 =	3.12
I can make decisions about how many animals or plants to use when I am doing an investigation.	6	3.11
I can make conclusions.	7	3.02
I can analyse data.	8	3.01
I can make hypotheses (predictions).	9	2.98
I can do an investigation where there is more than one changing factor.	10	2.88
I can say when it is appropriate to apply what I have found to other situations.	11	2.82
I can justify my conclusions.	12	2.76
I can re-design experiments when my first results are unconvincing.	13	2.69
I can identify the sources of error in my experimental method.	14	2.68

Analysis and discussion of findings

The "declared confidence" scales indicate that the students express more confidence with regard to the more mechanical aspects of carrying out an investigation and much less confidence with aspects of an investigation which require analysis and critical thinking.

The correlation coefficient for the total confidence ratings of the 98 students with their expressed confidence at aspects of planning an investigation was 0.85, indicating a clear positive correlation.

The survey data were enriched by discussing the outcome with the students involved to provide further elaboration of their responses. Three of the four classes were involved. The students indicated that they could not remember having to make decisions regarding such things as numbers of animals or plants to use, the number of times an experiment could be repeated, and possible sources of error in a method. Rather, they indicated that in previous experimental work at Form 5 they had usually been following a method which had been given to them by their teacher. A high percentage of the students had carried out investigations for Science Fair projects but did not immediately relate these experiences to classroom investigations. Others, however, indicated that Science Fair work was much more demanding than classroom practical work.

> In a Science Fair project you are doing much more thinking for yourself. You are not getting fed information from the teachers on what the results should be. You are actually getting your own results and making decisions for yourself. (Form 6 girl - personal conversation May 1993)

This survey analysis has resulted in the formulation of questions for the developing research. How can students be encouraged to reflect on the process of investigation? Would students benefit from the opportunity to repeat experiments rather then moving on to the next 'topic'? Is there poor transferral of cognitive skills from one practical situation to another. Can the transferral of skills be increased? If so, what strategies could encourage this transfer?

STUDENTS' PLANNING OF AN INVESTIGATION IN A GIVEN CONTEXTUAL SITUATION

Method

Immediately following the administration of the survey described above the students were asked to plan an investigation to test a hypothesis relating to a particular context described in Box 1.

Box 1 Green streams!

A small very slowly moving stream flows through the corner of your school grounds. You have noticed that the water has become much greener than it usually is. When you discuss this with other members of the class someone mentions that the school playing field had been fertilized recently. Had the fertilizer washed into the stream? Perhaps an increase in the amount of these chemicals present in the stream had caused the increase in the numbers of small plants. © Mavis Haigh

The students were given 15 minutes to plan the investigation individually, followed by 20 minutes where they worked in small groups to arrive at a group plan. They were encouraged to write down the method with as much detail as they could, and to use labelled diagrams to illustrate their method if they wished. If they changed anything they were asked to indicate this modification and say why they made the change. They were also told that at the end of the individual working time they should be ready to "argue the case" for their method.

In addition to producing a written record of the group plan the students were asked to indicate

* those aspects of their original plan which were not used in the group plan and the reason for this non-use; and
* those students whose ideas were used most.

While the groups were preparing the group plan one group from each class was audio-taped. Their discussions have been transcribed and analysed.

The individual and group plans were collected and rated according to a score sheet designed to reflect the original statements regarding "planning an investigation" in the confidence survey. The aspects were rated for Strong indication/ Moderate indication/ Weak indication/ No indication at all, scored 4/3/2/1. The mean and standard deviation of the actual planning scores were compared with that of the students' declared planning confidence scores.

Analysis and discussion of findings

A significant number of the students tested for presence of the fertilizer in the stream water. A smaller number planned to investigate the relationship between fertilizer concentration and the density of small plants in the stream. The scoring method allowed for this variability in response.

The students demonstrated most difficulty with aspects related to obtaining reliable results. Most students did not plan to repeat the experiments or use an appropriate sample size.

The correlation coefficient for individual and group planning scores over the total student population was 0.44 indicating a moderate correlation.

A first look at the relationship of 'group scores' to the individual scores of the members of the group indicates that in some instances the group plan scored lower than the plans from some, or all, of the individuals in the group. It appears that this was partly determined by the group member who had most influence over the group decisions, as indicated by the students. In several cases a workable plan was rejected in favour of a less rigorous design. Further analysis of this data is being carried out.

Analysis of the audio-tape material from four groups of students designing the group plan for the "Green streams" investigation indicates that the students:

* have some understanding of the need for careful control of variables and the use of a control. In one short 10-minute transcript the students used the term control six times, e.g. "Would it be called a control like if, say, we got a sample of the fertilizer and mixed it with water?"

  or the idea of controlling variable is implied, for example, when they were discussing how to get plants for the green streams investigation

  S1 No, if you get them from the pet shop ... anything else could have happened to them...
  S2 But at least they are the same ...
  S3 They are the same...

- have some understanding of the time span necessary for completion of the investigation, e.g. "Yeh, how would you watch them [plants growing in fertilised stream water] though? 'Cos it would just take so long, you know."

- have difficulty in making decisions regarding the required accuracy and frequency of measurement taking, for example, after a discussion as to how long to take measurements of plant growth

  S1 A week!
  S2 Oh, not a week
  S3 It wouldn't take that long

  and

  S1 Observations of what?
  S2 No, you need measurements because you can hardly say, "OK Bigger than yesterday" because you can't remember how big it was yesterday so you will need to take measurements.

- often do not put all the information they have down in writing, for example, one of the boys says clearly "Just put insufficient knowledge to test pH levels" but on the written sheet this is translated by the scribe as "didn't know how to test"

  and

  S1 Take two artificially cultivated samples of ...
  S2 Spell it, take...
  S1 Artificially ....[not spelling, just repeating]
  S2 Why not just say samples ...? [which is written down]

  [T3 students 5/4/93 - transcript]

Group planning transcripts also record cooperative decision making and indicate that group discussion triggers ideas.

The students' mean planning confidence score was 18.61 (SD 2.22) and the students' mean actual planning score was 11.13 (SD 2.28). A two-tailed, t test for paired data indicated a significant difference in these means at the 5% probability level.

This phase of the research suggests the following questions for further investigation:
If students are encouraged to write in their own words the hypothesis (prediction, question) that they are investigating will this enhance focussing on the investigation? When individual planning is followed by group planning what is the effect on the design? Would student understanding of the process of investigation increase if they are encouraged to discuss this with each other and with their teachers?

STUDENT PLANNING OF A COMPLETE INVESTIGATION

Introduction and Method

Although carrying out an investigation can be divided into phases such as focussing, planning, information gathering, processing, interpreting and reporting, the process is not sequential and students will be modifying their plans and actions as they proceed. To assess and evaluate student ability in this regard the students were given a complete investigation to plan and carry out. (Box 2)

Box 2 How much Factor X?

Imagine that you are working for a company that extracts substances from living material. You are asked to find a good source of a substance called Factor X (for secrecy purposes). It is known that Factor X occurs in a wide variety of living things. Previous investigations have shown that Factor X occurs in potatoes, celery, broccoli and carrots.

A simple test for Factor X is to pour a small quantity of hydrogen peroxide on to the material which is thought to contain Factor X. A foam is produced. The amount of foam produced indicates how much Factor X is in the material. Your job is to find the best source of Factor X from the four given plant materials.

Your employer wonders if it may be possible to preserve the plant material by heating it to boiling point so that it can be stored until it is required. Does this heating affect Factor X?

You will need to tell your employer the reasons for your decision. You do not need to worry about extracting Factor X.
You are provided with the plant materials as well as some apparatus which should be helpful.

HINT: Remember to carry out a "fair test". You may need to consider the amount of the living material which you use and the surface area of this which will react with Factor X..

© Mavis Haigh - adapted from Gayford (1989)

This investigation was timed to coincide with the topic of enzymes which some of the students had already studied and investigated experimentally. Others had neither studied enzymes nor carried out any enzyme-related practical activities. The teachers involved filled in a sheet indicating these factors and any other information they considered relevant to student achievement. Students were given a work sheet which included spaces for them to write the hypothesis in their own words, their initial plan, an indication of any modifications they may have made to their plan, their data, and their "report to their employer".

Analysis and discussion

At the time of preparation of this paper, two of the four classes had completed the investigation and returned the worksheets. The students in one class had previously carried out a similar investigation into the activity of enzymes in liver following detailed instructions. The other students had no previous practical or theoretical experience of enzymes. Each group is discussed separately.

Students with previous experience relating to enzymes. I had briefly discussed the findings of their "Green Streams" planning activity with this group. All students were able to make a personal prediction relating to the investigation. Analysis of both their written records and the transcription of their group discussion indicates that the students were carefully considering techniques for improving the reliability of their results. The areas covered in their discussions included:

an attempt to keep variables as constant as possible, for example they talked about:

- whether or not all samples had to have the skin removed;
- whether the samples had to be of the same size and weight;
- whether the samples had to be ground up with a mortar and pestle, and
- how much of the hydrogen peroxide had to be used.

precision with experimental techniques, for example they considered:

- whether the boiled vegetables needed to be cooled to room temperature before the addition of hydrogen peroxide;
- what kind of measurements they should take; and
- that several kinds of measurements could be used.

The students wished to use a control, though just how this was to be accomplished, and what was appropriate was sometimes rather uncertain:

S1 I sort of thought we should use a control for the experiment like freeze one, boil one and then leave one at room temperature.
S2 But you weren't asked to freeze one.
S1 I know, but you've got to use a control.
S3 Use the one at room temperature.
S2 Yeh, but why freeze it?

In general the transcript records considerable conferring regarding the experimental procedures the group was to follow.

The mean planning score for the students in this class who had planned both "Green streams" and "Factor X" increased from 10.9 (SD 3.7) to 12.4 (SD 3.4). A two-tailed t test for paired data indicates a significant increase in these means at the 5% probability level. This could indicate that, with practice, there is a slight increase in the ability to plan an investigation.

Students without previous experience relating to enzymes. The teacher did not give each student a task sheet to read but instead read the task through twice, instructing the students to write down important points. All students used the set work sheet. I had not discussed the findings from the "Green streams" planning activity with these students before they carried out the Factor X investigation. The students had recently investigated the rate of change of weight of potato cubes in different sugar concentrations. The written records of the initial plans and modifications to these indicated that:

- the students could write out what they were expected to do in their own words and make a prediction;
- the students related this exercise to the procedures used by them during a recent investigation;
- the students made modifications to their planned approach after group discussion;
- the students found it necessary to make modifications to their experimental design as they progressed through the investigation;
- eleven of the 23 students in this class were thinking about possible sources of errors in their method; and
- the students had not reported that they had considered the need to repeat their experiments.

The mean planning score for the students from this class who had planned both "Green streams" and "Factor X" increased from 11.9 (SD 2.5) to 12.8 (SD 2.2). A two-tailed t test did not indicate a significant difference in these means.

This phase of the research suggests the following questions for further investigation. How does immediate previous theoretical study and practical experience influence decision making during an investigation? What is the best way to give feedback and support to students regarding the process of practical investigation?

IMPLICATIONS FOR CLASSROOM PRACTICE

Students beginning a study of biology at Form 6 bring with them the practical skills they have developed and practised in the junior secondary school. Much of the practical work at the junior level is teacher-directed with students following set instructions. If students are to make a transition to open work in Form 6 biology then the initial findings from this research indicate that many of the students require guidance regarding what is expected of them, support while they are engaged in open investigations, and feedback regarding their techniques and findings.

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POST-PRIMARY SCIENCE TEACHERS' PERCEPTIONS OF PRIMARY SCIENCE EDUCATION

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ABSTRACT

Post-primary science teachers in Victoria were asked to express views about primary science curriculum design and implementation. They were also asked about the value of continuity between primary and post-primary science education. The post-primary teachers generally had favourable attitudes to primary science education and considered that cooperation would be useful - though it is not common at the moment. However, the data revealed a considerable range of opinion. Post-primary science teachers' views about primary science curriculum are similar to those of primary teachers themselves, but many post-primary teachers would place more emphasis on formal or textbook knowledge. Post-primary teachers see a number of systemic problems in implementing primary science education but their positive perceptions suggest the value of encouraging more structured links. The notion of continuity across the two sectors was well supported.

INTRODUCTION

The lack of continuity of school science education across the interface between the primary sector and the post-primary (secondary) sector has been a matter of some interest for many years (Williamson, 1981; Barber & Mitchell, 1987; Dawson & Shipstone, 1991). The issue of continuity has been made more significant because of teacher beliefs that primary science, while important and often exciting for both children and teachers, is often inadequate in terms of time and resources, teacher knowledge, teacher confidence, and program quality generally (Jeans & Farnsworth, 1992). There is also a strong possibility that the views of science education may be different among teachers at the two levels. Teachers' knowledge and beliefs about science education are a significant factor in how they respond to innovation and change and in their willingness to be involved in program development and renewal.

The past decade has seen renewed interest in the structure of schooling and in the interface between primary and post-primary schooling. There has been heightened awareness of the need to develop better primary science education programs. This has well documented for the United Kingdom (Sheldrick, 1991) but it true of many countries. It is now considered to be so important that central governments want to be directly involved as was the case in Australia when in 1989 the Commonwealth government reviewed science education in teacher education programs (DEET, 1989). Science education programs have changed over the last two decades and one result is that many more children are entering post-primary schools with a greater exposure to the ideas and skills of science - the overall effect is uncertain but the trend is reasonably clear. Some scholars have concerned themselves with models of articulation of primary and post-primary curricula and have helped clarify the different approaches that might be taken - for example, a "clean slate" view or a "build on" view (Barber & Mitchell, 1987). It is also apparent that there are differences in "style" and that there are major differences in the belief systems of primary and post-primary teachers. In some cases beliefs are so firmly held that they work against the smooth transition of students from one school sector to the other. They certainly work against curriculum continuity. There has however, been interest in the extent to which specialist post-primary science educators and primary teachers can collaborate for the improvement of science education at the primary level, and its articulation with science education at the post-primary level (Ministry of Education, 1987).

Different teacher education programs, different school organisations and different role structures have all combined to produce and maintain two distinct cultures -the generalist primary (or class) teacher and the post-primary specialist (or subject) teacher. These cultures should not be dismissed as surface manifest-ations of minor differences between people engaged in a common task. The differences are deep-seated and are sustained by many environmental or contextual factors. There is little doubt that the different value systems inherent in the two cultures have inhibited effective liaison and cooperation between the sectors. As is so often the case in human affairs, lack of detailed knowledge about science education in the two sectors has led to misunderstandings and generalisations of doubtful validity. For example, Barber & Mitchell (1987) reported that some post-primary science educators thought that: primary teachers are not sufficiently trained to teach science; they pick out all the best experiments so that by the time we do them properly the children are bored; the children are supposed to have done science but they can't even measure properly; safety education can't be done properly at primary level.

We suggest that there are also misunderstandings on the part of primary teachers. However, these are different in content. In general, the effect of such misunderstandings is to lower teacher confidence because post-primary science education is seen as highly academic and requiring special equipment. Furthermore, it is highly probable that the perceptions that many primary teachers have of post-primary science education is based on their own, unsatisfying experiences of science education in the post-primary school (Appleton, 1992; Segal & Cosgrove, 1992). Negative perceptions of post-primary science education are not restricted to primary teachers and awareness of this effect has led to significant attempts to improve the quality of science teaching and learning at the post-primary level (Baird & Mitchell, 1986; Bunder, 1992).

In order to understand better the scope and content of post-primary science teachers' beliefs about primary science education, a multi-purpose questionnaire was designed to determine the perceptions and opinions of post-primary science teachers about a variety of aspects of primary science education. These include the importance of articulation between primary science education and post-primary science education, the nature of the primary science curriculum and its effects, the administration of primary science education and resources for it, gender issues in science education and teacher factors affecting the provision of science education.

PROCEDURE

The questionnaire consisted of three groups of items. Nine items were concerned with biographical data such as school, age or age-range, gender and qualifications. There were twenty-five structured response items that elicited opinions concerning primary science implementation, organisation and importance as well as aspects of curriculum design and personal involvement in such design. The response scales for these items consisted of Likert-type continua (0 - 10) with 0 and 10 representing extreme views. For example item 1 was How desirable is it that there be continuity between primary science education and post-primary science education?. Not at all was scored as 0 and Essential was scored as 10. Six items sought further information or views and used a variety of response formats ranging from selection of words from a provided list (characteristics of primary science education) to a free-response item (suggestions for the improvement of primary science).

The questionnaires were sent to post-primary schools throughout Victoria and both government and non-government schools were included (roughly in numbers proportional to the total numbers in each category). Approximately ninety-five schools were contacted. The sample represented a random selection from each category of slightly less than one-sixth of the total number of Victorian schools. Principals were requested to pass the questionnaires on to members of their science staff for completion. For the statistical analysis, responses for an item were regressed on gender and on years of teaching experience. Where items did not have numerical responses brief descriptive summaries were derived.

The sample

Responses were received from 212 individuals (123 males, 89 females) in 63 schools (43 government, 20 independent) a response rate of 42.4% from individuals and 66.3% from schools. There was no attempt to follow up on contacts to achieve greater response rates but the authors consider that the sample is a significant group of Victorian teachers and the views expressed are therefore of great interest. Incomplete returns are a common outcome in this kind of research but in the present study all returns contained useful information and none had to be discarded even though some of the items had not been completed by some of the respondents. This was usually because the respondents did not feel that they had adequate knowledge. Ages ranged from 22 to 56; the mean age of the female teachers was 33.0 (standard deviation 7.58) and the male teachers 36.8 (7.57). The difference in mean ages was highly significant ($p<.001$). Respondents had been teaching for periods ranging from less than one year up to 33 years (mean 10.8 years) and for almost all of the sample (94%) classroom teaching was the major responsibility. Teaching duties were generally distributed quite evenly across the post-primary years with few teachers concentrating on particular year levels. Most teachers (64%) had taken part in-service or other courses during the past three years but few of these courses related to primary-secondary collaboration.

DISCUSSION

Importance of primary science education Four items related directly to the importance of primary science education and to continuity between primary and post-primary curricula. Some continuity was thought to be important (mean score 7.26, standard deviation 2.34) with 22% of respondents asserting that it was essential. When asked about the adequacy of knowledge of first year post-primary students the responses were normally distributed with a mean of 5.00 (2.08). This suggested that there was no specific concern about prior learning. Annotations to this item indicated that for a variety of reasons some teachers did not expect primary school children to know very much science content.

Teachers regarded the effect of primary science on attitudes to post-primary science education as of some importance (6.65, 2.48) but clearly did not see it as a fundamental variable. Despite this, primary science education was generally regarded as essential (8.38, 1.83). There was a significant ($p=.02$) gender difference and female teachers rated the importance of primary science more highly than males. These views should encourage those who seek to develop curriculum links between primary and post-primary science education. A number of teachers commented on the great variability of incoming students' knowledge and others mentioned their enthusiasm favourably.

Nature of primary science Many of the items had to do with aspects of curriculum development and matters of emphasis. Teachers did not see a need for primary science education to be a discrete subject (3.98, 3.00) and some teachers, by their additional comments, suggested the importance of developing links with other curriculum areas. These suggestions reflect a growing integration movement in which science education is linked with or integrated with social studies, language and mathematics. Just as there was little support for stand-alone science education courses there was only mild support for a fixed or prescribed grade-level course (4.57, 2.69).

There was a slight preference for process over content (5.86, 1.81) and a preference for "knowing why" over "knowing that" for primary science education (6.14, 1.96). There was an age effect for this item and younger teachers were significantly stronger in this view - p<.01. The idea that the principles of science should be illustrated was moderately supported (5.72, 2.28), a view that did not vary with years of experience or gender.

There was a reasonably strong view that primary science education should be comprehensive in its representation of science domains (6.84, 2.90) but there was ambivalence (less so for women p=.05) about the place of technology as part of, or replacing, primary science (5.17, 2.10). Some teachers pointed out that there was ambiguity in the question and that they would favour the inclusion of technology but not the replacement of science by it - others stated the view that technology and science are quite separate studies and should not be considered together. However, it was clear from responses to a following question that teachers strongly favoured a "how it works" approach to an approach involving principles where technology is to be linked to science (8.39, 1.94).

If a fixed or prescribed grade-level course is not to be provided for primary science then it would appear that school-based curriculum development is essential and one question tested teachers' views of this process. Teachers saw it as important (7.23, 2.23) though some comments pointed out its difficulties ("hard, time-consuming work") and suggested that "experts" need to be involved.

A further question of a different type asked for respondents' perceptions of primary science using free choice from 22 descriptors e.g. fun, difficult, messy, and relevant to everyday life. Thirteen teachers stated that they were unable to answer because of lack of appropriate experience and seven teachers suggested that the answers would vary according to the situation; some others gave "should be" type answers. The most common descriptors were: fun (115 responses); finding out (89); practical (64); investigating (59); relevant to everyday life (52); what if? (49); thought provoking (46). Many other positive descriptors were represented but in smaller numbers. The least common descriptors represented were: time consuming (8 responses); not relevant (5); repetitive (4); boring (3); incomprehensible (2).

The less favourable descriptors were least represented in the responses. The responses to this item tend to confirm, and add to the view, that primary science education is essential. They also indicate that it has, or should have, many positive characteristics (in the views of post-primary teachers).

Post-primary science teachers' involvement with primary science Two items asked for information about levels of actual and desired involvement in primary science education curriculum design. The actual involvement appeared to be very low (1.17, 2.29) but teachers clearly would like to do more (4.54, 3.05). This interest could no doubt be developed in future plans for the improvement of school science education at both levels. Other comments indicated that the time available for involvement would be a problem, and a number of teachers mentioned that they had already assisted in some such activities, for example providing inservice or lending equipment.

Teachers of primary science Three items probed post-primary teachers' views about the confidence of primary teachers and whether specialist teachers would be desirable for this curriculum area. On the question of confidence (even though 31 teachers did not consider themselves able to answer) the view was that lack of confidence was a major impediment (2.81, 2.15). In later comments some teachers felt that the build-up of confidence in teachers was a necessary pre-requisite to the improvement of primary science but there appeared to be little agreement about how this could be done. There was a wide range of views about whether teachers should be generalists or specialists (in one or a few areas). Generalist teachers were slightly supported (4.78, 2.72) overall but many teachers obviously see an important place for at least some specialists. A small number of teachers felt that it was not realistic to support primary science specialists. The idea of modifying the generalist teacher's role (specialising in two or three curriculum areas) was also not strongly supported (4.24, 2.65) and this may not be surprising since the multiplicity of teachers that students encounter at post-primary level can be regarded as a negative feature of this stage, resulting in shallow learning and lack of connection between areas of knowledge (Power, 1988).

Problems in organising primary science Primary teachers themselves see lack of equipment as a significant problem (Jeans & Farnsworth, 1992) (even though complex equipment is arguably not necessary or useful) and post-primary science teachers are often seen to be in a teaching environment which is much more liberally supplied with materials. It is probably not surprising that these teachers also saw lack of equipment as a problem (6.11, 2.75) although some noted that equipment should be simple and related to everyday life and the point was also made that there was a lack of facilities such as wet areas suitable for science in primary schools. A few teachers mentioned that they had assisted primary schools with equipment but there did not appear to be any strong feeling that primary and post-primary schools should cooperate in this way. A separate room for science was not regarded as very important (4.87, 3.07) and some teachers pointed out that such a room could discourage ongoing projects and tend to divorce science from everyday life and other aspects of the curriculum. One respondent suggested that the need for a separate room would vary between year levels.

When asked to choose (from a list) possible systemic problems for the teaching of primary science, the post-primary teachers chose four problems as of great significance. These were lack of knowledge (148 responses), inadequate materials (118); difficulty in organising materials (100); and lack of assistants to help with preparation, etc. (91). The next problem chosen by number of responses was lack of suitable texts (44) and lesser numbers were given for safety matters, gender bias, timetabling, etc. It is perhaps not surprising that these chosen problems corresponded in a general way with those chosen by primary teachers themselves in the study mentioned above. Primary teachers however would possibly not see lack of suitable texts as a problem (they did not do so in the earlier study), and, if so, this would probably reflect a different set of learning objectives for the two levels. This question could be investigated further but the authors believe that most primary teachers, at least in Australia, would use curriculum guides in preference to texts (if texts present material for children rather than for teachers). It is hoped that the BSCS (1992) materials which are presently being adapted for use in Australian primary schools will fill a need recognised by teachers in this study and will be acceptable to primary teachers as aids to curriculum development.

Gender aspects of teaching/learning The questions relating to separate classes, styles or topics for girls and boys were freely commented on by respondents and were not restricted to primary science. There was little value seen in separate classes at primary level (2.30, 2.86) and this was also evident in the study of primary teachers' views by Jeans & Farnsworth (1992). For post-primary science however there was more acceptance of separate classes (4.61, 3.51) particularly by women ($p = .02$). Few teachers believed that there were many topics more suitable for girls than for boys (1.26, 2.16) but those who did mentioned topics such as consumer science, family patterns, environmental surveys and biological topics or those requiring less mechanical knowledge/aptitude. There was greater acceptance of the idea of teaching styles which would be more suitable for girls (2.83, 3.07) and examples given included styles which involved group work (many responses) and problem-solving, creative writing, open-ended investigations, cooperative learning, active encouragement to promote self-esteem and descriptive rather than formal language. A number of teachers (at least 7) recorded their opposition to differential treatment by gender with comments such as "Nature is not gender specific" and views that good teaching methods are equally suitable for girls and boys.

Items with open-ended responses Teachers were asked to suggest specific topics which ought to be in a primary science curriculum and the responses were many and various - there were approximately sixty-six topics represented and the most common were: plants (29 responses; animals (25); astronomy (24); environmental studies (23); simple chemistry - kitchen, etc. (18) responses. The other topics given ranged widely across all areas of science e.g. scientific method, health, observation, the human body, machines, all elicited around 10 responses. These responses were similar to those given by primary teachers in an earlier study (Jeans & Farnsworth, 1992).

The time given to primary science education has been regarded as too low in the past and is often less than one hour per week (Jeans & Farnsworth, 1992). Most respondents in this study favoured 1-2 hours as the appropriate allocation (106 responses) but about 80 preferred a longer period (from 2 to 5 hours). This suggested increase in time has to be seen against the background of perceived confidence and practical implementation problems, and would clearly need a considerable effort if it were to be implemented; this was noted in some responses which distinguished between ideal and realistic allocations.

Post-primary teachers' lack of knowledge of the primary science context was demonstrated by the question which asked for recommendations about suitable texts or curriculum guides. There was clearly little knowledge of books written specifically for the primary level: The science framework (Ministry of Education, 1987) was mentioned 20 times and other answers ranged from Science Teachers Association of Victoria publications to some older activity books and a few junior post-primary texts. If, as sometimes suggested, post-primary teachers become resources for primary science education, they would also need professional development designed for this purpose. This professional development would be unlikely to succeed if post-primary science teachers assumed that the structures and content of post-primary science education were a suitable foundation for designing a primary science education curriculum. The authors suggest a collaborative model of organising science education across the primary/post-primary boundary (Ministry of Education, 1987).

When asked for suggestions for the improvement of primary science, the respondents produced a variety of suggestions, the most common of which can be paraphrased as: the provision of more inservice (32 times); more consultation between primary and post-primary teachers in neighbouring schools (19); teacher training (initial) should be improved (14); science should be a specialist area (10).

There were many other suggestions given once or a few times and some notable ones were: total integration of science into the general curriculum; more reliance on a coordinator; a set curriculum guide with easy-to-prepare activities; the linkage of science to children's out-of-school lives; the removal of stress on "scientific" ideas and equipment (keep it simple and interesting); the provision of more time, expertise and resources.

Many of these suggestions were also contradicted by other suggestions expressing the opposite view. The variation of views can be illustrated by such statements as "I like to see primary science as a gathering of observations and experience and, wherever possible, not to involve extensive use of "formal" science equipment" and "Don't get too carried away - most students are turned off science by year 9. If science is taught as a subject earlier, we may find difficulties at level 7 or 8." Incidental comments were included on many response forms and a number of these have been given above where appropriate. Others include such views as: the experience of science in post-primary school is often negative (prospective primary teachers are often turned off by science); any content is valid so long as it is interesting and taught with enthusiasm; primary schools should follow a watered-down year 7 curriculum (!); post-primary teachers do not expect science knowledge in entering students but find it most marked in relation to astronomy and living things; primary science should avoid and actively discourage traditional stereotypes. There was some mention of the belief that primary teachers do not always relate experiments to principles well, and that in such cases the content and experiments would be better left until post-primary level.

CONCLUSION

Post-primary teachers of science in Victoria appear to have favourable attitudes to primary science education and to appreciate its importance. Many of their views about the nature and implementation of primary science education appear to be similar to those of primary teachers surveyed in a previous study by the authors. However it is clear that few teachers have had much involvement with primary science education either as curriculum designers or as interested colleagues of primary teachers. Often the only semi-direct knowledge seemed to come from primary-age children in the family. While it is true that primary and post-primary science education may be seen with some legitimacy to have different goals, the management of the transition from year 6, in Victoria, to year 7 in the post-primary school does not appear to have been well considered. Dawson and Shipstone (1991), in considering the adoption of a National Curriculum in the United Kingdom have pointed out the need to ensure continuity and progression. They also noted the lack of empathy, though this appears to be changing, between teachers of the two levels and the likelihood of different teaching styles. This was most evident in variations in ordering of the importance of objectives. Where primary teachers saw problem-solving as particularly important, post-primary teachers favoured manipulation of apparatus and "formal" experimenting techniques such as control of variables. In the present study the congruence of objectives was not directly tested but it would appear that one of the major differences is in the importance assigned to the use of texts by post-primary teachers and this would presumably indicate a belief that, at both levels, knowledge of science facts and concepts would be of considerable importance. We believe that primary teachers would probably prefer experiential teaching- learning that facilitates the development of concepts and skills. Primary teachers might be less concerned with textbooks and formal science equipment. This speculation needs further investigation, but it is in accord with the study that we reported in 1992. There are many problems in the implementation of primary science education and there are significant pressures at present to specify learning outcomes more completely at all levels (the National Curriculum movement). In this study and in the study of Dawson and Shipstone (1991), post-primary teachers demonstrated favourable attitudes to primary science education. They regarded it as of importance in its own right and as contributing to science education in general. They appeared to believe that cooperation between the two levels of science education is important. There were some other differences too - in the English study it would appear that post-primary teachers were fairly confident of the scientific knowledge and confidence of their primary colleagues. The present study in Victoria does suggest that post-primary teachers would probably not rate primary teachers' knowledge and confidence so highly. It is however possible that the difference may be due to the greater development of liaison and cooperation in Derbyshire (Dawson and Shipstone (1991) report its development there over a period of five years). The authors would suggest that it is time for systemic change in which there will be greater cooperation and liaison between science educators at primary and post-primary levels. This may mean some re-thinking at both levels and it should clearly not mean that the approaches common at either level should become universally accepted. In particular we support the view expressed by Barber and Mitchell (1987):

> the best primary science is not only well worth building upon, but also represents a much better approach to science education than that so often provided in the early years of secondary school. (p. 5)

If this has any truth at all, it is in spite of well known difficulties at the primary level: less-qualified teachers, lack of a resource base and the need for integration of science education into the whole curriculum to a greater extent. Teachers and science coordinators at the post-primary level may be in the best position to encourage liaison and exchange of views. This study suggests that their views are such that the building of better science education links is a real possibility at this time.

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TOWARDS A THEORETICAL BASIS FOR STUDENTS' ALTERNATIVE FRAMEWORKS IN SCIENCE AND FOR SCIENCE TEACHING

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ABSTRACT

As there is nothing as practical as a good theory, there is a continuing need in the field of science education enquiry to look for theories which help to interpret the findings about students' alternative frameworks and to inform the design of teaching strategies which relate to a research focus on 'how the student learns'. The developmental model of cognitive functioning based on the SOLO Taxonomy (Biggs & Collis, 1982) as updated in 1991 (Biggs & Collis, 1991; Collis & Biggs, 1991) is being applied in this way. Questionnaire data from two large studies of science learning of Australian students (conducted by ACER and NBEET) are being re-analysed in terms of the current theory. This paper illustrates the theory and describes a plan of further research.

INTRODUCTION

Four criteria related to teaching and learning are fruitful foci for research. These are: 'what the student knows' prior to formal science teaching; 'what the teacher knows'; 'how the teacher teaches'; and 'how the student learns'. The first three of these criteria have received attention in addressing the pedagogical problems of science teaching arising from students' alternative frameworks of understanding (SAF) about aspects of natural phenomena. The choice of some new teaching approaches has been based on a constructivist epistemology and has been informed by beliefs about the value of students sharing their diverse views in supportive environments (e.g. Brook, 1987; Smith, Blakeslee & Anderson, 1993). Consistent with the common adage that 'there is nothing as practical as a good theory' there appears to be a need in the field of science education enquiry to look for theories which help to interpret the SAF findings and inform the design of teaching strategies which relate to the fourth focus, namely, 'how the student learns'. The following description outlines the application of a developmental model of cognitive functioning based on the SOLO Taxonomy (Biggs & Collis, 1982; updated in 1991) in an attempt to achieve these ends. The theory is illustrated with reference to students' responses to questionnaire items about 'vision' and a plan of further research is described.

SOLO TAXONOMY AND MULTI-MODAL FUNCTIONING

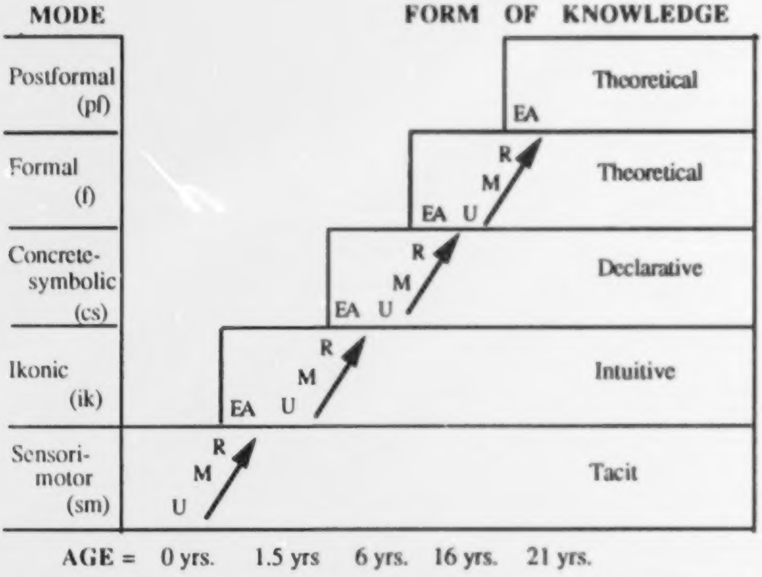
The SOLO Taxonomy (Biggs & Collis, 1982) has been used to analyze the structure of children's understanding of mathematical concepts and problem solving abilities over a wide educational span from primary to tertiary levels (e.g. Chick, 1988; Pegg & Davey, 1989; Watson, Chick & Collis, 1988; Watson & Mulligan, 1991). It has been applied in a limited way in the area of science (Collis & Davey, 1986; Levins, 1992). The SOLO theory, which was significantly updated in 1991 (Biggs & Collis, 1991; Collis & Biggs, 1991) builds upon Piaget's stages of development and suggests a five-level cyclical *structure for responses* within each of at least five *modes of cognitive functioning*. The theory postulates that *modes of functioning* begin to appear sequentially from infancy and *each one* may remain operational and develop further throughout life. The modes, abbreviations and common ages of appearance are: *Sensorimotor* (sm: infancy), *Ikonic* (ik: early childhood to preschool), *Concrete Symbolic* (cs:

childhood to adolescence), *Formal* (fm: early adulthood), *Post Formal* (pf: adulthood), but they should not be confused with Piagetian stages. In earlier proposals each successive mode, with its increased level of abstraction, was seen as replacing its predecessor. However, with the recognition that the sensori-motor and ikonic modes provide their own distinctive forms of knowledge in adult life, they are viewed as developing throughout life, and in interaction with other modes. Such co-existence of qualitatively different forms of functioning provides the opportunity for multi-modal learning where learning within one mode is supplemented by experiences and activities in concurrent modes (Collis & Biggs, 1991).

Sensorimotor functioning is associated with the *performance* of skilled motor activities and relates to tacit knowledge, although one may be unable to *explain* how one interacts with the physical world. The ikonic mode is associated with intuitive knowledge, that which is perceived or felt directly and which involves the imaging of objects and events. Functioning in the concrete symbolic mode involves the use of symbol systems which have referents in the material world and facilitate the communication of declarative knowledge. Lastly, the formal and postformal modes are the most abstract ones and involve theoretical constructs having no material referents. Within these modes individuals are able to consider not only what is perceived to be real but what may be possible.

The cyclical *structure* for responses within each mode, in order of increasing complexity, features

- * prestructural responses (P) which represent no use of relevant aspects of the mode in question;
- * unistructural responses (U) which represent the use of only one relevant aspect of the mode;



KEY: U - Unistructural M - Multistructural R - Relational EA - Extended Abstract

Fig. 1 Relationship between modes, levels of response and forms of knowledge
(Adapted from Biggs & Collis, 1991)

- multistructural responses (M) in which several disjoint aspects are processed, in sequence;
- relational responses (R) in which several aspects of the mode are related into an integrated whole;
- extended abstract responses (EA) which make use of higher order principles and may take the whole process into a new mode of functioning at the unistructural level or another cycle within the same mode.

Fig. 1 (adapted from Biggs & Collis, 1991) shows the transition between modes of functioning and the equivalence of the extended abstract response of one mode with the unistructural response of the next mode.

Recent work in mathematics on Volume Measurement (Campbell,Watson & Collis, 1992) and Fractions (Watson, Collis & Campbell, 1991) suggests that there are in fact two major cycles for this kind of content within the concrete symbolic mode. The first shows heavy reliance on the IK mode to develop the concrete concept and the second uses the CS mode as such but utilises ikonic support for problem solving (see Table 1).

OVERVIEW OF THE STUDY

Initially, questionnaire data from two large studies conducted by ACER (Adams, Doig & Rosier, 1990) and NBEET (1993) of science learning of Australian students are being re-analysed in terms of of the SOLO Taxonomy and its current theoretical underpinnings (Biggs & Collis, 1991; Collis & Biggs, 1991). In the ACER study, data were obtained from representative samples of 2665 students in Grades 5 and 9 in the state of Victoria. In one part of the study children were shown sets of cartoons depicting selected everyday phenomena related to six science concept areas. The children were invited to verify certain cartoon statements and to write explanations of how or why some things were so. In most cases about 1000 students completed each set of stimulus cartoons. In the NBEET study a sample of 1161 students in their last year of primary school (age 11-13 years), and from all states of Australia, were given a five-part questionnaire. This included parts to assess process skills, conceptual understanding in science and attitudes to science. In the conceptual understanding section students were invited to respond to 24 written questions related to a wide range of science concept areas.

General Plan

The researchers involved in the current study obtained random samples of 50 scripts in each of four of the six concept areas in the ACER study and 150 scripts from the NBEET study for analysis. Children's responses are being re-analysed in terms of their structure according to the SOLO Taxonomy and its recent theoretical developments relating to modes of functioning. On the basis of this analysis further questionnaire items will be developed in a small number of topics and administered to children across the age groups from Grades K-10 to fill gaps in the available data. Individual interviews of selected students will be conducted to clarify their written responses and to validate inferences made about responses from the various samples. Hypotheses will be developed about the order of, and influences on, the development of concepts, and typical ages (if any) at which critical shifts in modal functioning occur. It is believed that the theory, when applied in relation to specific science topics, may be sufficiently fruitful to contribute to the design of more effective teaching approaches which enhance a student's scientific understanding of the topics and the ability to make higher level responses in appropriate modes. We propose to implement and evaluate such designs in the topics studied.

TABLE 1
LEARNING CYCLES OF LEVELS OBSERVED IN RELATION TO THE CONCEPT OF VOLUME OVER SCHOOL GRADES.
(Based on Campbell et al., 1992)

MODE	GRADE	LEVELS	GENERAL FEATURE
Sensori-motor			
		ik.U1	
Ikonic		ik.M1	
	K	ik.R1	Concepts associated with intuititions, feelings and /or images about real objects or events.
	1		
	2	ik.EA1 cs.U1	Lessening reliance on ikonic support for concept.
		cs.M1	
		cs.R1	Concrete symbolic concept, as such, developed.
Concrete Symbolic	5/6		
		cs.U2	Increasing reliance on ikonic support for problem solving.
		cs.M2	
	9/10	cs.R2	Concrete symbolic concept generalised.

Probing Students' Understanding About Vision

Visual sensing is a dominant part of everyday experience from early childhood and thus the topic of 'sight and light' has much potential for the engagement and interest of children in school science across a wide age range. It also has potential for responses over the range of modes of functioning. Both sets of available data contain responses to questions dealing with beliefs about how people see objects and the role of light in this process and their study is likely to build upon the seminal work of Guesne (1985). Hence, this topic was chosen to be explored first. An analysis of responses to the ACER questionnaire related to 'vision' is the focus of this paper.

Stimulus Items

In relation to 'vision', six sets of cartoons were used in the ACER study to 'tap students' science beliefs' about whether light is an entity, whether light travels and the relationship between light and vision. The final cartoon is a single line drawing of two children apparently looking towards a tree in a field with hills in the distance and a cloud in the sky, as shown in Fig. 2. Students were invited to complete and label the picture to explain how light is needed for us to see and below it to write an explanation of their diagram. The actual question was: "Can you complete and label this picture to explain to the children how light is needed for us to see ? Explain your diagram."

RESULTS

The responses to the picture completion /explanation item were grouped in order of their relevance to the question and the degree of complexity of the drawing and written statement in each. Four groups of responses were readily identifiable and these were then associated with ikonic and concrete symbolic SOLO modes. The four categories with their descriptors are set out in Table 2 along with suggested modes of functioning that the responses appear to reflect. Also, the numbers of children shown in each category are based on a sorting by

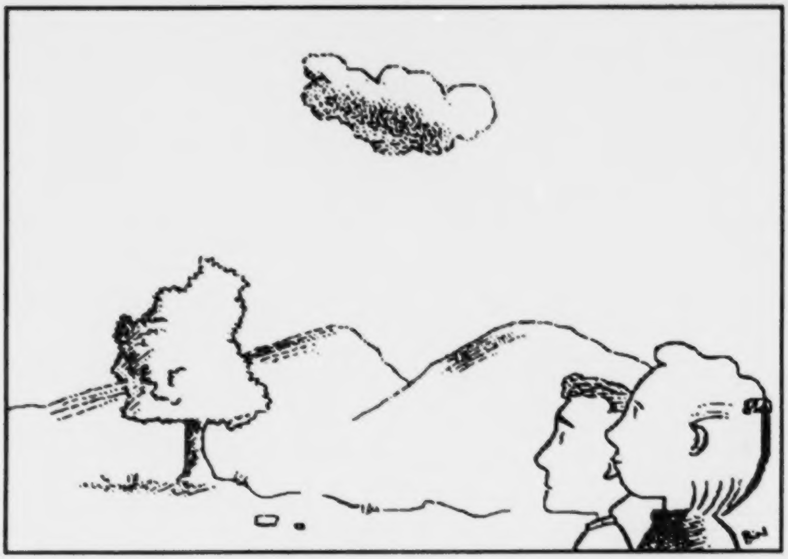


Fig. 2 Cartoon from ACER questionnaire (Adams, et al. 1990, p. 120)

the first author. On the basis of the criteria, a second sorting by an assistant gave a very similar result with an inter-rater reliability of 0.88.

Structure of responses: modes and levels

Some examples will serve to illustrate the structure of different responses to the ACER item. Each extract is followed by an ID code in brackets (in the order of Grade, gender and number) together with the SOLO mode and UMR response level.

* Ikonic mode (low level). Where responses use only one relevant aspect, or use aspects which are irrelevant to the set task, they are considered to be low level compared to those using two or more relevant aspects. Furthermore, these levels may be related to particular alternative views about vision referred to below. The responses in Category 0 (Table 2) were all low level ikonic and the following are typical:

> If there was no light it would be freezing (9b6) ik.P
> Light is needed for us to see our land and all of our beautiful nature (5g7) ik.P
> ...light makes us see (5g9) ik.P

The first statement, from a boy in Grade 9, may be partially true but as far as the given cue is concerned it is irrelevant. The other two responses are also true but are tautological in this context as they merely repeat the concepts of the cue. All three responses are at a prestructural level in relation to the concrete symbolic mode.

In Category 1 a range of ikonic responses was obtained, from unistructural to relational within that mode, and were either in the form of drawings or words. The most common relevant aspect was the Sun, used either as an example of light or a source of light although it was not possible to be sure which meaning was intended in every case. Although the following two responses repeat the 'light' cue given in the question, they do add one concept relevant to an explanation, albeit an alternative one, of how light is needed for us to see. Imaging is a prominent feature in both.

TABLE 2
CATEGORIES OF RESPONSE TO ACER PICTURE COMPLETION AND EXPLANATION QUESTION AND NUMBERS IN EACH CATEGORY BY GENDER AND GRADE*

CATEGORY + CRITERIA	**Boys**		**Girls**		**TOTALS**	
	Grade		**Grade**		**Grade**	
	5	**9**	**5**	**9**	**5**	**9**
Category 0 = Ikonic						
i. Drawing: No addition to picture given.	(4)	1	(1)	3	(5)	4
ii. Irrelevant or tautological or no response	(2)	1	(5)	1	(7)	2
					(12)	6
Category 1 = Ikonic						
One or more of:						
i. Drawing: Sun drawn in correctly (for shadows given)	(3)	4	(3)	2	(6)	6
Sun drawn - position not correct.		-	(4)	2	(4)	2
ii. Statement to the effect that Sun makes light.						
iii. No mechanism stated (or shown) for light travel or for seeing.		1	-	-	-	1
					(10)	9
Category 2 = Concrete symbolic + Ikonic support						
No reference to a mechanism for "seeing". One or more of:						
i. Drawing: Sun drawn correctly (for shadows given)			(3)	4	(3)	4
Sun drawn - position not correct.		2	-	3	-	5
ii. Objects are 'lit up', become 'bright', made 'visible' by light.						
iii. Sun is stated to be a source of light - rays or beams travel to or shine on objects and can be blocked.						
					(3)	9
Category 3 = Concrete Symbolic						
A mechanism for "seeing"+ evidence of a concept of reflection, + One or more of:						
i. Drawing: Radiation with Sun/ object/ eye connection shown		1	-	-	-	1
ii. Use of word 'reflection' or equivalent (in sense of 'bouncing')						
iii. Light enters eye and brain interprets.						
					-	1

* Numbers in brackets are for Grade 5 , n = 25 (9b + 16g)
Other numbers are for Grade 9 , n = 25 (9b + 16g)
(Respondents counted for drawing may have written words also but were not counted twice.)

> If...no light you couldn't see...it would be pitch black (9b13) ik.U
> If there was no light everything would be in complete darkness (9g9) ik.U

In these two unistructural responses the ikonic concepts of 'pitch black' and 'complete darkness' suggest a belief in the common view that we see because things are bathed in a sea of light. This may represent the 'ambient light' view in which no vision mechanism is stated. It is the first of Guesne's (1985) four alternative views of vision. This view is also the likely basis of a third example:

> If the sun was not out the children would not be able to see anything (5g24) ik.U.

* Ikonic mode (higher level). In the second, or 'bright object', view of vision objects are believed to have a degree of brilliance that makes them visible because light from a source is directed towards, or hits, those objects. However, as in the first view, there is no object-eye connection such as light 'travel' or reflection. This view is possibly the basis of a second set of Category 1 responses in which no eye-vision mechanism was shown yet two aspects relevant to the context were stated with a logical connection which may be transductive.

> The sun produces light which makes things visible (9b14) ik.R
> ...the sun is making them (things) bright for us to see (5g21) ik.R

These are examples of relational level responses in the ikonic mode because two images are linked. A source of light and an effect are logically (perhaps tautologically) related in each statement but there is no use of any concrete symbolic element. However, such responses may be seen as precursors to the more concrete symbolic concepts of rays, beams and reflection which mark the next category.

* Concrete symbolic mode with ikonic support. Each response in Category 2 indicated an advance on those already outlined by showing evidence, in the text and or drawing, of concrete symbolic thought together with ikonic support. In each of the following there is a reference to notions such as rays, movement of unseen entities or concrete metaphors like 'beating down', e.g.

> The suns rays will reflect down on the earths surface (9g23) cs.U1
> If light hits something it creates a shadow (9g21) cs.U1
> The sun beats down and lights up the place so people can see (5g23) cs.M1
> [+ Drawing: bright objects + arrows drawn from Sun]

It can be noted in the first unistructural case that, when taken in conjunction with her additions to the drawing, the word 'reflect' appears to be used in the sense of rays travelling. The next case is unistructural because the second aspect mentioned appears to not be directly relevant in the context. The third response is multistructural in that it sets out a sequence of relevant (partly ikonic) elements. It falls short of the integration needed to give it an R1 classification. All three responses appear to indicate the use of the 'bright object' view of vision although the multistructural response in the last case might be seen to favour an 'ambient light' view.

* Concrete symbolic mode (with lessening ikonic support). The only response considered to indicate mainly concrete symbolic functioning was that of a boy in Grade 9 whose diagram shows dotted lines connecting Sun, tree and eyes. His written explanation states that,

> The eyes use the projection from the sun on the object and use the light to tell the brain (9b25) cs.R1

Although the word reflection was not used it seems clear that this was the idea being conveyed graphically and that the 'projection from the sun' refers to transmitted light from Sun to eye via an object. Thus, there are three or four relevant aspects, logically related in an explanation of vision consistent with the currently used scientific one. He appears to have a degree of facility with the concrete symbolic system of school science but in this context does not show evidence of generalisation to an extended abstract level that might indicate the onset of formal functioning in this topic. In such a mode one would expect responses to involve the use of theoretical concepts such as 'radiation' and 'energy' in such a way as to indicate an understanding that these concepts do not have concrete referents, but are elements of a model which mimics an event but is not part of it. Evidence of the third view of vision in which 'bright' or 'visible' objects are 'looked at' by the eyes by means of beams, or the motion of other entities, was not found.

Overall summary of the responses

Over one third of the whole sample either did not add to the drawing or gave written responses judged to be irrelevant or tautological in that they used the question to trigger off an affective or intuitive response typical of low level ikonic functioning. A further 38% gave responses seemingly based on intuition which identified the Sun and its light as the only requirement to explain vision. They used concepts about things that could be directly perceived and imaged, a characteristic of ikonic thought. In all, 74% of the responses were judged to represent ikonic functioning. The remaining 26% included some reference to concrete symbolic concepts such as 'rays' and light 'travelling' to 'hit' objects. The majority of these were from Grade 9 children with only a very small minority (6%) from Grade 5 (the responses of three girls). Most of the responses in this group were also considered to represent concrete symbolic functioning but with ikonic support. Only one person, a boy from Grade 9, made a clear reference to 'seeing' and his response included a mechanism involving light rays and a source-object-eye connection. The symbolic concept of reflection was conveyed diagrammatically in his drawing. No responses included a form of words to refer unmistakably to reflection, e.g. 'some light rays from the sun bounce off the tree and enter the eyes of the children'.

DISCUSSION

Views about vision

The various alternative explanations of vision which have been reported in the literature (e.g. Guesne, 1985) involve the use of one or more components related to 'light' or 'seeing' or both. Light can be (i) ambient, (ii) directed to objects which become brilliant, and (iii) reflected from objects. Sight can be (a) passive seeing (b) active 'looking' with a movement of something between eye and object and, perhaps, its return, and (c) reception by the eyes of light from objects and processing. In the scheme of analysis used in the present study, these components of responses can range from ikonic through concrete symbolic and ultimately to formal. We suggest that components (i), (ii) and (a) are related to imaging the world as directly perceived and are thus largely ikonic whereas (iii), (b) and (c) involve abstractions of a concrete symbolic nature. Thus the first of Guesne's (1985) four views of vision involves (i) + (a); the second (ii) + (a); the third (ii) + (b) and the fourth (iii) + (c).

Evaluating responses using the SOLO model

Levins (1992) classified written responses of secondary students to concept words related to the evaporation of water and postulated two UMR cycles in the concrete symbolic mode. However, in her limited study of a small group of seven year old children, all their verbal responses were judged to be in the ikonic mode. That the responses of most of the younger children in the present study represent ikonic functioning is an extension of this finding and consistent with current SOLO theory (Biggs & Collis, 1991; Collis & Biggs, 1991). However, the fact that only one person out of 25 older children, from Grade 9 in this preliminary study, showed evidence of the concrete symbolic mode (without much ikonic support) is interesting. Perhaps most of the secondary students in the sample were not taught concrete symbolic notions related to this topic before the survey or, perhaps, prior teaching was ineffective.

Alternatively, the questionnaire may not have cued declarative knowledge within a developed symbol system. This finding is consistent with Guesne's (1985) claim that for French speaking children the development of the important symbolic notion, that light must penetrate the eyes after propagation in straight lines, may be generally beyond the age of 14 years.

It is worthy of note that most of the alternative views about vision, implicit generally in the responses, seem to have their bases in ikonic functioning.

Some problems of interpretation

The SOLO Taxonomy is a 'response' model, therefore the size of the net which is cast to sample the conceptions of individuals will affect, to some extent, the overall evaluation of the responses given. Some cues may evoke different response modes, and levels within modes but, since we recognize the context dependence of knowledge, we are not aiming to make global assessments of people. The purpose of the taxonomy is to evaluate responses in contexts of appropriate size. The context probably requires the consideration of the question type as well as the nature of the context: factors which have not always been controlled in studies reported in the science education literature. Thus, the Category 2 response of a Grade 9 girl who added only a few labelled objects to the drawing but wrote,

> All of the objects labelled have light shining on them...but there is parts...where there is no light because the sun can't get through (9g20),

was considered to represent concrete symbolic functioning at a multistructural level (cs.M1) with ikonic support. However, in other contexts in the same area of knowledge she appeared to respond at a relational level (cs.R1), e.g.

> Light goes until it reflects off an object
> Light is something to reflect off different things so we know what they look like.

Whilst it was relatively easy to apply the SOLO Taxonomy reliably to evaluate responses, it wasunderstandably difficult in some cases to be sure of which alternative view of vision a child was using. Further investigation is necessary to determine the nature of relationships between SOLO levels and modes and students' alternative understandings (frameworks) in this and other topics.

CONCLUSION

A key hypothesis behind this research is that, unlike other concrete symbolic systems which first become important at school, the explanation of many aspects of natural phenomena have been important to children some time before this. Children have already applied their sensorimotor and ikonic notions to construct explanations consistent enough with their experiences and other knowledge to be adequate for their everyday lives. Thus, many contexts in school science are not new like those which occur in mathematics, reading and writing but are old contexts in which students have some well entrenched systems of personal meaning. These alternative conceptions seem to arise from a mixture of the first three modes of functioning, perhaps in different proportions according to the particular topic or phenomenon in the context. We propose that teachers' lesson planning is likely to benefit from the application of a theory which provides a structural interpretation of students' common responses to key phenomena in school science studies.

As this study is developed further we plan to look for developmental cycles of responses within the structure of specific subject matter of school science, as well as relationships between SOLO modes and levels and students' alternative understandings. The eventual objective is to facilitate students' understanding of the concrete symbolic systems of science.

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TEACHING PROBLEM-SOLVING SKILLS: A REFLECTION ON AN IN-SERVICE COURSE FOR CHEMISTRY TEACHERS IN SINGAPORE

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ABSTRACT

A unit on the teaching of problem-solving skills, part of a chemistry in-service course for 25 experienced secondary school teachers in Singapore, presented two strategies: think-aloud and general problem-solving strategies. The evaluation of the unit was based on teachers' personal evaluations and their answers to a questionnaire which focussed on their responses and attitudes towards the teaching and learning of problem solving while using the two strategies.

INTRODUCTION

Informal observation of students' problem-solving behaviour, as well as some systematic studies, indicate that there are some common difficulties associated with teaching and learning problem solving. These include:

- lack of science knowledge pertaining to the problems (Woods, 1988/89);
- lack of an organized, hierarchical knowledge structure which can be easily remembered and appropriately retrieved in complex contexts (Reif, 1983; Woods, 1988/89);
- lack of problem-solving skills such as translation and linkage skills. Students have difficulty in translating the problems into meanings and in setting goals or subgoals for the problems, especially the unfamiliar ones. They also have difficulty in linking the appropriate knowledge from their minds to the novel problem situations (Lee, 1986; Bunce, Gabel & Samuel, 1991).
- lack of knowledge of a problem-solving strategy and of the procedure for problem solving (Reif, 1983; Camacho & Good, 1989). It is not surprising that some problems are left unattempted by many students especially if they are new to them.
- lack of experience and confidence in problem solving (Camacho & Good, 1989).
- lack of emphasis on the systematic organisation of the thinking process required for problem solving. Teachers emphasize the strategy which directly uses rules or algorithms for solving the problems. Their sense of problem solving strategy is more than a strategy of using rules or algorithms for a typical type of problems. This is evident from the way they perceive the problems, pull the information together, and check their solution (Lee, 1986).

Students' failures in problem solving could possibly be attributed to their lack of sufficient experience in problem-solving lessons. Methods commonly used by teachers rely predominantly on presenting information, showing prototypical examples of worked-out problems, and giving students practice in solving similar kinds of problems. All too often our teaching methods encourage passivity among students. It is possible that the failure of students to develop the ability to solve problems is not because they are unable to do so, but because we have not been explicit enough in illustrating what it is. Improved methods of teaching problem solving are necessary to strengthen our students' problem-solving ability and skills.

Woods (1984, 1985a, 1985b) has designed a problem-solving program (the McMaster Problem Solving Program) for an Engineering Course at McMaster University in Canada. A unit of the programme employs Whimbey's think-aloud approach (Whimbey, 1984; Woods, 1985a) to develop awareness of process skills while solving a problem. One student works the problem with a partner who does not directly participate in problem solving but forces the problem solver to verbalize all thought processess. This approach has been proposed as a valuable resource in teaching science students how to solve their homework and personal problems (Woods, 1984; Carmichael, Bauer & Robinson, 1987; Pestel, 1993). Whimbey's Think-Aloud Pair Method is also used for introducing a problem-solving strategy namely, 'McMaster 6-Step Strategy' in another unit of the programme (Woods, 1985b). This consists of 6 stages of solving processes which include: (1) Read/I want to and I can, (2) Define, (3) Explore, (4) Plan, (5) Do it, and (6) Look Back. Both units let students take charge of their own learning by identifying clear goals and the routes to achieve these goals.

This paper reports how the think-aloud and general problem-solving strategies were introduced to a group of experienced chemistry teachers from Singapore by employing the Whimbey Think-Aloud Pair Method. It also discusses the teachers' responses and attitudes towards developing problem-solving skills during the workshops.

METHOD

Sample

Twenty five experienced chemistry teachers from twenty schools in Singapore took up the chemistry in-service course (March-May 1993) organised by the National Institute of Education. The course was spread over 10 weekly sessions, each of 3 hours. The author was scheduled to teach problem solving in two consecutive sessions in the middle of the course. The experience of these teachers in teaching chemistry at secondary level (equivalent to Grades 7-10) ranged from 3 to 19 years.

Procedure

Two problem-solving strategies, namely Think-Aloud Strategy and General Problem Solving Strategy, were introduced in the two workshop sessions. Think-aloud was taught in the first session and General Problem-solving in the second. In both workshops, the time was divided into three parts. The first 45 minutes was used for a lecture followed by a discussion with the teachers on background information such as the rationale for teaching problem-solving skills, the instructions for the activities for learning the two strategies. The teachers were then given about 100 minutes to practise in pairs solving problems using these two strategies. First, content-free problems were used and then were followed by chemical problems. The content-free problems used to introduce the methods were taken from Whimbey and Lochhead (1986). For the last half-hour, teachers were asked to give feedback about the workshops.

Workshop 1: teaching of Think-Aloud Strategy

The objective was to make teachers aware of the process and to be able to verbally describe the process whereby they solved problems. For the Whimbey's method, the teachers formed pairs among themselves: one was the problem solver, and the other the listener. The method demanded that the problem solvers verbalize all procedures and manipulations. The listeners did not directly get involved in problem solving but encouraged verbalization. The instructions for the problem solvers and listeners are shown in Appendix 1. Each problem solver was given a content-free problem to work on. The teachers reversed roles when finished. A discussion session followed with the teachers talking about their reaction towards the activity. After this the teachers repeated the same activity but this time they used chemical problems. One example of the content-free and chemical problems is shown in Appendix 2.

Workshop 2: teaching of General Problem Solving Strategy

The objective set for this workshop was for teachers to become familiar with the McMaster 6-Step Strategy (Table 1) and its general application. The teachers obtained feedback on how they saw the stages as they worked through the content-free and chemical problems.

The teachers were advised to extend the use of Whimbey's method in this workshop to describe aloud the mental processes they were using. At the same time the 'problem solver' had to identify which of the six stages in the McMaster 6-Step Strategy they were in by placing the marker on the strategy board (Table 1). The role of the listener was the same as in Workshop 1: to encourage verbalization. Listeners had to remind problem solvers to indicate which stage they were in and to speak aloud all thought processes. As in Workshop 1, each teacher was given one content-free and one chemical problem to solve.

TABLE 1
THE McMASTER 6-STEP STRATEGY

1. Read/I want to and I can
2. Define *understand words, analyze statement, identify constraints,* *identify criteria, draw diagram*
3. Explore *play around with ideas, make connections, collect information*
4. Plan *start to get serious, begin to formulate steps*
5. Do it
6. Look Back *check, double check, identify experience factors, extend to* *other problem, implement, what is learnt about problem solving*

Instrumentation

The responses and attitudes of the 25 teachers towards the developing of problem-solving skills were sought using a personal evaluation sheet for each workshop and a questionnaire for the overall presentation at the two workshops. The personal evaluation sheets contained open-ended questions which allowed the participants, as the problem solvers and listeners, to describe what they had learned about problem-solving skills during the workshops.

The questionnaire consisted of 10 items of two subscales on a 5-point Likert scale. It was designed to investigate the teachers' view in two different aspects. The two subscales are: (1) learning and teaching PS skills (items 1, 3, 4, 5 and 10) and (2) Using PS skills by students (items 2, 6, 7, 8 and 9). Five of these items are positive and five are negative. Responses were scored 5 for strongly agree; 4 agree; 3 neutral; 2 disagree and 1 strongly disagree, for the positive items, with scoring reversed for the negative items. Cronbach's alpha values for the two subscales were 0.70 and 0.77, and 0.86 for the whole questionnaire.

FINDINGS

Two sets of data were obtained. The first was the teachers' personal evaluation of what they learned from the two workshops and the second their responses to the questionnaire.

Teachers' Personal Evaluation

The teachers were asked four questions in the evaluation sheets for the two workshops. The responses from the teachers for the 4 questions were analyzed. The common responses for each question are listed in the order from the most to less popular among the teachers. The numbers of teachers who gave the same or similar responses are indicated in the brackets.

Question 1: As the problem solver, what have you learned about your own problem solving through the Whimbey Think-Aloud Pair Method ?

Responses

1. Checking the answer or solution (11)
2. Think-aloud problem solving is fun. Should do more of this. (10)
3. Reading and re-reading the statement to understand the problem (9)
4. The usefulness of think-aloud strategy (8)
5. Using pencil and paper (7)
6. Identifying key words (7)
7. Drawing diagrams (6)
8. Establishing links between facts (5)
9. Using relevant knowledge (5)
10. Being more systematic (5)
11. Being more careful (5)
12. Thinking and explaining more in detail (4)
13. Being more aware of own weaknesses e.g. jump at answer too quickly; having weak background knowledge on a particular area (4)
14. Looking for or focussing at the goal of the problem (3)

Question 2: As the listener, was it (Whimbey Method) an easy task ? What was the hardest thing to do ?

Responses

15. No. It was not an easy task. (21)
16. The hardest thing to do was
    a. to control the urge to give the answers (8)
    b. not to show the problem solver where she/he had gone wrong (4)
    c. to control oneself not to influence the problem solver while she/he was solving a problem (3)
    d. to control the urge of wanting to solve the problem (3)

Question 3: As the listener, what do you learn about the process of solving problems ?

Responses

17. The importance of checking including the re-reading of the statement when the problem solver is stuck (9)
18. Problem solvers need encouragement and assurance all the time (5)
19. The importance of understanding and interpreting the problem statement (4)
20. Problem solving involves a logical sequence of steps and process skills (3)
21. The importance of sound concept/knowledge required for solving a particular problem (3)

Question 4: As the problem solver, what did you learn about the use of strategy (McMaster 6-Step Strategy) from these activities ?

Responses

22. To be more aware of the stages involved in problem solving (11)
23. To make checking the important component of problem solving (10)
24. A need to spend more time for defining the problem statement (8)
25. To read and solve the problem aloud (6)
26. To identify key information from the statement (5)
27. To draw diagrams to help visualize the problems (4)
28. To link appropriate information which is either from the statement or memory (4)
29. The general strategy is a systematic approach (4)
30. To plan the solving procedure before solving a problem (3)
31. The need of explicitly teaching the stages of general strategy to students (3)
32. The general strategy helps organise your thought (3)

For Workshop 1, in general, the teachers enjoyed the activities conducted during the workshop. Many teachers considered the activities were fun (Response 2). The teachers admitted the usefulness of the think-aloud strategy (R4). Being slowed down in solving the problems due to thinking aloud, they became more careful (R11) and systematic (R10). They were also more aware of their weaknesses in problem solving (R13). They tended to think and explain in greater detail when they solved the problems by using the think-aloud method (R12). Many teachers commented that through the think-aloud activities they were more aware of their problem solving processes involved in solving the problems (R3, 5-9 & 14).

The majority of the teachers did not find the listening task easy (R15). They found it hard not to tell the problem solvers the answers or not to give assistance to the problem solvers while they were solving the problems (R16 a-d). Some teachers stressed that the problem solvers needed encouragement and assurance from them all the time (R18). From being the listeners, some teachers learned that the checking of the solution, understanding and interpreting of the problem statement and sound background knowledge required for solving the problems are important for problem solving (R17, 19 & 21). Some of these points can be illustrated by using some of the teachers' comments quoted as follows:

- Being a problem solver and listener in these activities, I realise that learning is a process and it takes time and steps. If we can analyse how the students think by experiencing it personally, somehow we can bring this knowledge back to the classroom. This is what the course has taught us. Thanks. [Teacher 9]
- I find that I am more aware of the need to have more focus on what I am trying to solve. There is also a need for a strategy to solve a given problem. [Teacher 11]
- I noticed that I highlighted the key words in the problem and to verbalize my approach in solving the questions, I would draw diagrams to illustrate while explaining to the listener. It was fun as it is related to logical thinking. [Teacher 18]
- I tended to write some other sub-concepts, linking one idea to another until I was confident enough to go ahead. After the answer was found, I would go over the whole problem again. [Teacher 22]

For Workshop 2, the teachers recognized the importance of the general strategy as it helped the problem solvers to be more aware of the stages involved in problem solving (R22). The general strategy is a systematic approach and it helps organise thought (R29 & 32). Some teachers saw the need of explicitly teaching the general strategy of problem solving to students (R31). The teachers also commented that they had learned different problem-solving skills through the general-strategy activities. The learned skills being highlighted by the teachers include: (1) reading and solving aloud (R25), (2) defining problems by spending more time at this stage (R24). The techniques can be drawing diagrams (R27), identifying key words or facts from the statement (R26), (3) planning the solving procedure (R30), (4) linking the appropriate information (R28), (5) checking the answer or solution (R23). The following teacher's comment for Workshop 2 can be used to illustrate some of the above findings.

> It's important to follow some steps systematically rather than plunging into answering the questions straight away. Using a strategy helps to keep my mind thinking, gathering relevant information so as to visualize the problem better, before taking action. Checking through after solving ensures that the answers are correct and I find it important. [Teacher 13]

The Questionnaire

The means and standard deviations scores were computed from the questionnaire data, for the whole questionnaire, each of the two subscales and for each of the ten items. The mean score per item for the whole questionnaire was 3.87 (s.d. 0.95), significantly different from 3 at the 0.01 level. This indicates a favourable attitude from the teachers towards the problem-solving skills introduced during the workshops. The means for subscales 1 and 2 were similar (3.84 and 3.89 respectively, both significant at the 0.01 level), indicating that the teachers were in favour of both the learning and teaching of the problem-solving skills and their use by students.

Table 2 reports the means and standard deviations for each item. All the means are above 3.5 and significant at the 0.01 or 0.05 level. This indicates that the teachers on the whole regard the teaching of problem solving to students as important. The teachers considered that the methods used for teaching problem-solving skills were not too abstract. The activities were enjoyable. Teaching the skills would not increase the complexity of the chemistry curriculum. The skills were considered as transferrable to areas other than chemistry. Students would not be expected to have great difficulty in using the strategies. Problem-solving skills were regarded as likely to help students to be more systematic and confident in solving problems.

DISCUSSION

The main goal of this study was to seek the views of some Singaporean teachers on developing students' problem-solving skills through the use of think-aloud and general problem-solving strategies. The findings, based on the two measures, one qualitative and the other quantitative, show high consistency among the teachers' responses. The teachers were in favour of the approaches used in introducing these strategies during the in-service course.

The think-aloud and general problem solving strategies make the problem solvers responsible for their own learning in problem solving. The teachers recognized the usefulness and importance of these strategies which can be used to develop problem-solving skills. They believed their students would benefit from the skills in future problem solving; this is supported by the scores on the 'Using PS Skills by Students' subscale. The role of listener is important (though not easy) because the listener is not only there to promote vocalization by the problem solver but also to learn to appreciate the difficulty the problem solver might have. With this experience teachers are able to understand better their students' difficulties in solving problems and offer help accordingly. The teachers realized that problem solving was more than an answer or a solution: "Problem solving involves a logical sequence of steps and process skills." Just offering an answer or a solution may not necessarily help students develop their problem-solving skills. The teachers agreed that teaching problem-solving should be explicit in all processes involved, especially translating and checking processes. For the translation of problem statement, the teachers considered that identifying the key

TABLE 2

MEAN AND STANDARD DEVIATION OF EACH ITEM IN THE QUESTIONNAIRE (NO. OF TEACHERS = 25)

Item	Mean (S.D.)	Significance
1. It is important to teach the problem solving strategy for my purpose as a teacher.	4.28 (1.02)	$P < 0.01$
2. Using the strategy, students are able to describe to others their mental process of problem solving and any difficulties encountered.	3.76 (0.72)	$P < 0.01$
3. The strategy is too abstract for me to learn.	4.00 (1.04)	$P < 0.01$
4. I find learning the Whimbey Pair method of teaching problem solving enjoyable.	3.56 (0.87)	$P < 0.05$
5. Chemistry is already complex; teaching this strategy makes it more complex.	4.04 (0.55)	$P < 0.01$
6. The strategy would help students how to solve problems more systematically.	4.00 (1.14)	$P < 0.01$
7. The strategy CANNOT be used by students in areas other than chemistry.	4.00 (1.22)	$P < 0.01$
8. Students will have great difficulty in using this strategy for solving problems.	3.83 (0.76)	$P < 0.05$
9. Using the strategy will make my students demonstrate greater confidence in solving problems.	3.68 (0.99)	$P < 0.01$
10. The claim about its bringing about better problem solving skill is NOT TRUE.	3.52 (0.87)	$P < 0.05$

information from the statement and drawing diagrams to help visualise the problems are important problem-solving skills.

From the problem-solving processes highlighted by the teachers before and after the introduction of the general problem solving strategy in Workshop 2 (see the responses to Q1 and Q4), it was evident that many teachers, to some extent, had been practising some of these skills in their problem solving. This confirms the comment made earlier that teachers do have a sense of strategy in problem solving. Nevertheless, they might be unaware of the processes taking place during their problem solving. The ideas they had about problem solving, however, were not systematically organized for the effective teaching of problem solving. Comments made by one teacher sum up this point:

> I have become more aware of the mental processes I use to solve the problems. As pointed out by others, we have always adopted the strategy unconsciously. Through these activities there is increased awareness and hopefully a more effective approach to solving problems. [Teacher 21]

IMPLICATIONS

Among the six areas of difficulties associated with the teaching and learning of problem solving described earlier in this paper, the first two areas concern knowledge base and require other kind of attention in teaching. In the other four areas, difficulties can probably be overcome through the effective teaching of problem-solving skills. Based on the positive results of this study, the think-loud and general problem solving strategies are recommended to be taught in schools for solving problems in chemistry or other science subject areas. Students should be given more practice on solving problems by using Whimbey's method to improve their problem-solving skills and confidence in solving problems. Content-related problems should be carefully designed: they should not only be challenging but manageable within students' ability. With the two methods mentioned in this paper, the individual problem-solving skill such as translating, linking and checking skills can also be emphasized and taught independently to students for a wider range of learning experiences.

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Appendix 1

Instructions for Whimbey Think-Aloud Pair Method

BEING THE PROBLEM SOLVER

Rationale:

You should acquire the skill of being aware of what you are doing while you solve problems, of being able to identify where you are in the process of solving a problem and of being able to describe to others what you have done and where you are stuck (if you hope to gain assistance from your listeners). These skills usually have to be developed. One way to try to develop them is to slow the process down and describe or write out what you are doing. Another way is to solve a problem following a set of instructions given to you by somebody else and identify what instructions were awkward for you. In this exercise, we use the former method. However, instead of working on your own, you will have one of your colleagues serve as a "mirror" for you, to help you see what you are doing. Your partner will not give you any hints on how to solve the problem. Your partner will help you describe what you are doing.

Details:

1. Adjust the chairs so that you and your partner are comfortable and suitably seated about a worktable.
2. Make sure that you have paper, pencils, computer and anything else you might want to solve the problem.
3. For any particular problem you are solving, there may be hints or suggestions given in the write-up on how to solve that type of problem. Both you and your partner should discuss these before you start. Your partner may remind you to use these hints as you are solving the problem.
4. Read the problem aloud.
5. Start to solve the problem on your own. You are solving the problem. Your partner is only listening to you; he/she is not solving the problem with you.
6. Thinking aloud is not easy. At first, you may have trouble finding the right words; don't search for these - say whatever comes into your mind. No one is evaluating you. You and your partner are trying to help each other.
7. Go back and repeat any part of the problem you wish. Use such words as "I'm stuck; I better start over.", and "Let's see...hmm.".
8. Try to solve the problem no matter how trivial you think it is or no matter how little you think you are learning. Most do not realize the fantastic improvement that occurs when they work these exercises. It will be difficult for you to see success in yourself. For this reason, when you have completed the problem, you might find it useful to record what you learned about problem solving from the problem you have just solved. Fill this out on your own. Then perhaps your partner will be able to add some ideas about what you have learned.

BEING THE LISTENER

Rationale:

You have a key and challenging role to play. You are to help the problem solver see what he/she is doing and to help improve his/her accuracy in thinking. This requires first that you encourage — indeed, force — the problem solver to constantly talk about what he/she is doing. Next, you should monitor the problem solver's progress so that the correct solution is obtained and so that your partner will improve his/her accuracy in thinking. Finally, you should encourage ideas to be presented — no matter how foolish they may sound — and yet not provide hints yourself. You must never give the correct answer.

Details:

1. Establish as quickly as possible that you will be a question asker and not a critic. Explain beforehand that you are not criticizing when you ask such questions as "Please elaborate.", "Can you tell me what you're thinking now?", "Don't worry how it sounds - just say an idea, it doesn't even have to be a complete sentence.", "Please let me hear what you are thinking about.", "Does that sound right?", "What next?", "Can you check that?".
2. Restate your role as one to:
   (a) demand constant vocalization, yet do not keep interrupting when the problem solver is thinking.
   (b) help him/her improve his/her accuracy.
   (c) help reflect the mental process being followed.
   (d) make sure that you understand each step that the problem solver is taking.
3. Do not turn from the problem solver and work out the problem on your own - actively follow and track the problem solver's procedure in solving the problem.
4. Do not let the problem solver continue if:
   (a) you do not understand what he/she has done.
   (b) you think a mistake has been made.

   If you think a mistake has been made, ask him/her "to check that", or "Does that sound right?", "Are your sure?". If the problem solver still does not see the error, then point it out, but do not correct the error.

Appendix 2

Content-Free Problem (Whimbey & Lochhead, 1986)

In a different language *luk eir lail* means "heavy little package," *bo lail* means "heavy man" and *luk jo* means "pretty package." How would you say "little man" in this language?

Chemical Problem

Nickel and cadmium plates were placed in a solution of sulphuric acid. When the outer ends of the plates were interconnected with a wire, hydrogen began to evolve at the surface of the nickel plate. Can we decide which of the metals stands farther to the top in the electrochemical series? Express the reaction by an equation.

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A DECADE OF DEBATE ON THE SCHOOLING OF GIRLS IN PHYSICS: WHERE ARE WE NOW?

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ABSTRACT

The last decade has seen an explosion of interest in issues concerned with girls and science education, and the nature of the dialogue has become increasingly sophisticated. Current writing stresses the importance of acknowledging differences between women, as well as differences between women and men. This paper will outline some of the positions it is possible to adopt in the discussion. It will raise some questions concerning the implications of the choice of a position for classroom teachers of science and, in particular, physics teachers.

INTRODUCTION

A central dilemma facing many of us concerned with issues of equity in science classrooms is the choice of language with which to describe and explain the apparent under representation of women in the physical sciences. The dilemma is not unique to science classrooms, or confined to secondary schools, but is increasingly recognised as a difficulty being faced throughout education. Andrea Allard (1992), speaking of a gender inclusive curriculum writes:

> In trying to identify what a gender inclusive curriculum might be, we become tight-rope walkers. On the one hand there is the danger of falling into an unquestioning acceptance that differences between the sexes are "normal and natural" and of being seen to be endorsing those differences by continually talking about women's ways of knowing as in opposition to men's ways of knowing. We re-emphasise the differences rather than building on commonalities.
>
> On the other hand, we can fall into the pit of trying to ignore those constructed differences and of the way schools operate to reinforce and unequally value differences. We then fail to connect with how our students make sense of their lives, particularly as they define themselves in terms of 'masculine' or 'feminine'. (p. 14)

The metaphor of tight-rope walking is particularly vivid in this context. It implies the existence of a tenuous middle ground which it is possible to occupy safely, while emphasizing the inherent instability of the position. It is possible to successfully negotiate a tight-rope, but only by the application of skill and care. Consider, for example, the question of gender equity in the science classroom. If one asks for science courses which acknowledge and value the skills traditionally ascribed to women, one runs the risk of being seen as demanding a separate (perhaps inferior) science for girls who "can't cope with the real thing". On the other hand, if one asserts that women can and should take their place alongside men in science as we know it, one may collude in a process which devalues the traditional skills of women, and forces girls into being socialized in a manner traditionally reserved for men.

The dilemma can be paralysing – in order to avoid saying the 'wrong thing' one says nothing at all – yet an understanding of how this situation has arisen can prove most illuminating. I propose, with selective reference to the discussion concerning the schooling of girls in physics over the past decade, to identify how that discussion has changed, and comment on the various views of women and science which have allowed the changes. Inevitably, these comments will be informed by my personal experiences of working for change in school physics classrooms during this period.

The difficulties involved in our language of gender are discussed in detail by Evelyn Fox Keller (1989). She identifies the problem as one of the meaning of gender and its relation to sex on the one hand, and, on the other hand, its relation to difference in general. The term sex is used in this case to refer to the biological reproductive characteristics with which we are born, while gender refers to the behaviour or characteristics usually designated 'masculine' or 'feminine'. Keller makes the following distinction:

> gender is neither simply the manifestation of sex, nor simply an easily dispensable artefact of culture. It is, instead, what a culture makes out of sex - it is the cultural transformation of male and female infants into adult men and women. (Keller, 1986, p. 172)

She attributes the difficulty encountered in maintaining the middle ground to an implicit contest for power. Much of her writing explores the nature of this contest: what is at stake, why is science as it is and men and women as they are?

WHY FOCUS ON PHYSICS?

A cursory examination of statistics, over the last 12 years, of students enrolled in the final year of secondary schooling in Victorian schools, will reveal that all was not well with our physics classes. In 1980, 26770 students attempted H.S.C. (the Higher School Certificate, at that time the final examination in secondary schooling) in Victoria: 57.1% of these were female. Of these students, 9264 studied Biology, 7039 studied Chemistry, and 5496 studied Physics at year twelve. The proportions of these groups who were female were 71% in Biology, 41% in Chemistry , and 26% in Physics. Data for 1989, taken after a decade of curriculum reform, show increases in the total numbers of students studying Biology, Chemistry and Physics. The participation rates for girls in this year were: 70% in Biology, 55% in Chemistry, 27% in Physics. In 1991, Victoria embarked on a new Victorian Certificate of Education, with significantly altered assessment strategies, and a different approach to the teaching and learning of most subjects, including physics. The number of students attempting physics in the final year of secondary school in 1992 rose to 9850: 28% were female. The total number of girls studying physics in Victorian secondary schools has increased, but the fraction of the total number of students studying physics who are female remains effectively unchanged.

In the introduction to Science for Girls, Alison Kelly (1987) presents similar data for students taking science in the CSE and O level examinations in England. These data deal not with students attempting science subjects but with those actually passing these subjects, and are expressed as a percentage of the total number of school leavers. Kelly's conclusion from the data is that "the problem of girls and science is really a problem of girls and physics" (p. 6). The issues of participation rates and success rates are different. In Victoria, in 1992, 97.2% of the girls who attempted physics successfully completed the subject compared with 93.8% of the boys. Additionally, for the first time, girls out performed the boys in the higher grade levels. (See Hildebrand & Allard, 1993, for a discussion of these patterns and issues.) Generally, girls who choose to study physics are successful in their study. Yet, while the actual number of girls studying physics in secondary school in Victoria has risen from around 1400 in 1980 to 2735 in 1992, they still represent less than a third of the total number of students in final year secondary school physics in Victoria.

These sorts of statistics provided the stimulus to what Kelly has referred to as "an explosion of interest" in girls and physics education. Many possible explanations have been suggested for the low proportion of girls studying physics. (See, for example, Kelly, 1987; Harding, 1987; Kearney & MacDonald, 1987.) The debate continues, and to a large extent the question of why physics should be the subject which shows such marked differences remains unresolved. This paper is not concerned to identify and explore in detail each explanation offered for the existence of a "problem of girls and physics". It deals instead with the views concerning gender and science which shape both our framing of the problem and our responses to the explanations which arise from research into the area.

EXPLANATIONS OF DIFFERENCE

Evelyn Fox Keller (1986) identifies four stages in the responses of people to the juxtaposition of the terms 'gender' and 'science'. She points out that in our thinking about gender we continually slip between the idea that there are fundamentally two genders which may be clearly identified with biological sex, and the conviction that, really, the differences between men and women are only those of socialization, and that there need only be one gender. In this second position, there is the possibility that gender as a criterion for the division of the world into two may disappear. Carried alongside and interacting with these ideas concerning gender and sex are two possible positions regarding the status of science. In the first of these there is only one science, "mirroring the oneness of nature" (p. 171), while in the second we admit the possibility that there may be more than one science, reflecting the multiplicity of perspectives available. This second position rests upon the view that science is not a true mirror of nature, but is constructed by society.

I have found it useful to think of these views concerning science and gender as intersecting in a grid (Table 1), providing the four stages Keller identifies. While Keller's use of the word stage could imply some sort of hierarchical development of ideas, I prefer to think of the word 'stage' as representing a position, or point of view: a vantage point which can determine what one is able to see. In what follows I discuss some of the difficulties associated with each view.

TABLE 1
POSSIBLE POSITIONS IN THE DISCUSSION CONCERNING GENDER AND SCIENCE

	GENDER	
SCIENCE	DETERMINED BY SEX	CONSTRUCTED
DISCOVERED	**Stage 1** Two sexes and two genders, but only one science. The low number of women in physics is explained in terms of intrinsic biological differences. A deficit model for women	**Stage 2** Two sexes, but the possibility of only one gender. The low number of women in physics is explained in terms of different socialization. A deficit model for women.
CONSTRUCTED	**Stage 3** Two sexes and two genders, with the possibility of two (or more) sciences. The explanations for the low numbers of women in physics still focus on the differences between the sexes. A deficit model for science.	**Stage 4** One, two, or many genders, one, two or many sciences. Complete relativism for both gender and science.

Stage 1: A deficit model for women: intrinsic biological difference

In the first stage identified by Keller, both gender and science are implicitly presupposed as fixed. Gender is equated with biological sex, and science arises in a predetermined manner from the objective study of nature. Keller (1986) points out that "in this framing of the world, where there are two genders, and one science, the subject of gender and science ...immediately reduces to a discussion of "why women are unfitted for science". (p. 168)

This is a position which offers no hope for change. Girls are girls, science is science and the two will not meet except in the case of a few 'freaks' of nature: women with exceptionally 'masculine' intellects, women who are only suited to science because they are inherently unsuited to being women.

The possibility that this position could have some validity has been explored at length. John Head (1985) in The Personal Response to Science, summarises the situation;

> Perhaps the commonest possibility given in psychological literature [for the paucity of women in science and engineering] is of differences in cognitive abilities, women seen as inferior to men in mathematical and spatial skills and superior with verbal tasks. What is the evidence? Maccoby and Jacklin list 35 studies of quantitative factors, of which 16 showed male superiority, 4 female superiority and the remaining 15 no significant difference between the sexes. For spatial abilities 34 found male superiority, 5 female, and 62 found no difference. With verbal items 15 studies found male superiority, 42 female and 103 found no significant difference. Broadly speaking we can see some support for the common belief in differences in aptitudes but the very large number of inconclusive studies in each case should be noted. How important are these effects? Even when statistically significant differences are found they are usually only of the order of 0.2 standard mean difference (mean of standard deviations).
>
> .....only at the extreme ends of the ability range are population sizes sufficiently different to give a ratio between the sexes anything like those found [amongst students studying science subjects at secondary school and universities].
>
> There are enough women in Britain with all the measured cognitive skills to fill every post in science and technology, not merely gain their half share. (p. 54)

Head goes on to say that "there are many further reasons for doubting the importance of the relatively small differences in measured performance" in explanations for subject and career choice. Alison Kelly, (1987, p. 13) points out that in countries other than Britain, particularly in Eastern Europe, large numbers of women study science successfully. Closer to home, similar data has been presented for both physics and chemistry in Thailand (Klainin, Fensham & West, 1989): in both subjects girls and boys participate equally and girls perform at least as well as boys on practical tests involving manipulative skills and problem solving, theoretical tests of physics knowledge, and an attitude to science test. Significantly, in the practical tests, the girls at single sex schools outperformed all other groups.

If the cognitive abilities of women, as a group, are compared with those of men, as a group, it appears that the differences within each group are greater than the average differences between the groups. Examining data from different cultures would seem to indicate a strong cultural influence. Faced with data of this nature, one has to look elsewhere for an explanation of the phenomenon of the low numbers of girls in our physics classes, and thus we come to the second stage identified by Keller.

Stage 2: A Deficit model for women: Inadequate Socialization

This stage is one which regards women as unfitted for science not by nature but by socialization. The two genders are regarded as being constructed in opposition out of essentially identical raw material. Science remains absolute, men are socialized in ways which predispose them to the study of science, while women are socialized in other ways which unfit them for the study of science. To take an example from personal experience, an acquaintance told me recently what the problem was with girls and physics: the girls just weren't tough enough. They caved into parental expectations, and did what they were told, studying the 'wrong' subjects in high school. If the girls really wanted to do science they would have fought for it, not caring what anybody thought of them.

This line of reasoning is popular in many circles. It belongs to a family of explanations which invoke deficit models for women. Models which stem from this stage have two characteristics: they typically, as in the previous stage, locate the reason for the paucity of women in science within the women themselves, and they (quite logically) prescribe solutions which involve changing women. The task for a teacher who is concerned to ensure equal participation of women in the sciences becomes that of providing a safe and comfortable environment in which girls can learn to be boys, or at least to learn a sufficient number of masculine skills to compete with the boys at their own games, one such game being the study of physics. Not all proponents of deficit models are as unsympathetic as the one which I have quoted above: there is danger that many of our 'affirmative action' projects which are aimed at giving girls access to 'non-traditional' skills may fall into the same category.

Jane Kenway (1990) writes of the deficit model for women presented by much of this discourse, summarizing:

> When the focus (of the explanations for the under representation of women in physics) is on the girl, it is said that she lacks the appropriate aptitudes, attitudes and knowledge and makes the wrong choices. She, and her parents, are believed to be ill informed about women's current patterns of participation in the paid labour market and the changed nature of the family, and therefore they fail to recognise the likely realities of her future.
>
> The girl is said to be further deficient because she does not bring to 'non-traditional' school subjects a history of experience which facilitates her interest and success. Neither does she possess the 'cognitive style' which such subjects demand. (p. 3)

Most strategies which implicitly or explicitly invoke this model attempt to change the present situation by changing the girls. Tinkering, with toys or gadgets, is introduced to improve the competence of girls with machinery. Careers information is provided to encourage girls to consider 'non-traditional' areas of paid employment. Girls are offered role models of women in trades or science.

The focus of the strategies is to change girls: to alter their perspectives of what is possible and appropriate for them. There are, however, problems one encounters if these strategies are implemented in isolation. It is by no means obvious that the labour market of the future will be similar to that of the present. It may be argued (Willis, 1991) that the push to persuade girls to take up mathematics and science is a direct consequence of the loss of boys to more attractive and lucrative careers.

Further, at its simplest level, the discourse associated with these strategies underwrites the message that masculine is better. The steps run as follows:

1. The maths, science and technology domain is valuable.
2. This domain is traditionally masculine.
3. The reason that women do not participate in this domain is that girls are or have been brought up to be different from boys.
4. It is necessary that women participate in this domain (other areas are less valuable).
5. In order to ensure that girls enter this domain we change girls so that they are no longer different from boys, at least cognitively and affectively.

Keller (1986) writes of this process:

> Women had observed that the division of the world into two serves them poorly - it serves to exclude them from the domain of public life, of power, and of science. The claim that we are different meant that we are less. Quite reasonably, therefore, women fighting for admission the world of science countered with the claim, no, we are not different. But there's a hidden kicker in this move, that only becomes evident with the question: different, or not different, from whom? We are speaking of course of the problem that inheres in the fact that the universal standard is after all not neutral – of what happens to our strategy, and our thinking about gender and science when we begin to notice that the universal man is, in fact, male (p. 169).

The difficulty of this choice for feminists (see, for example, Kenway, 1990) is that it confirms a deficit model for women, affirming that to be masculine is to be socialized with superior skills. A masculinist science becomes the ideal against which we measure our women. Women, to suit science, must be socialized as men and thus be created in a manner alien to the majority of the women in society. It may be argued that implicit in the acceptance of this process is acceptance that men are better. In direct opposition to this process, however, we find recommendations that it is not women who must change, but science.

Stage 3: A deficit model for Science

The third stage identified by Fox Keller is to regard gender as fixed and immutable, but to regard science as a constructed entity. (Discussion of the processes of the social construction of science may be found, for example, in Kuhn, 1962, Whitehead, 1925, and Woolgar, 1988). It now becomes possible to reconstruct science in accord with one's image of woman, perhaps to provide a separate science for girls.

Solutions to 'the problem of girls and physics' which arise from this point of view also focus on the differences between girls and boys:

> Their [girls'] greater connectedness to the world through external objects means that every event is enmeshed in a complex web of inter-relationships; girls and women may continually be processing information from a much greater range of sources than do boys and men (Harding & Sutoris, 1987, p. 33).

However, rather than changing girls, the concern is to change the curriculum. Thus we have the spectrum of activities which constitute 'girl-friendly science': using examples drawn from girls' experiences, creative writing, role play, a wide range of assessment tasks aimed at valuing an ability to adopt a broad, global perspective on issues, and perhaps teaching in context. These represent excellent teaching strategies and should form part of every teacher's 'bag of tricks'. There is cause for concern, however, with the image of women which is implicit in the selection of these strategies as better for girls. What do we mean when we say something is 'better for girls'? Are these strategies better for girls than other strategies? Or are these strategies better for girls than for boys? And when we say girls, do we mean all girls, most girls, or some girls?

My point is that the search for 'girl-friendly science' often relies on an identification of the essential nature of womanhood. It is not necessary to believe in biological predestination in order to hold this view: much of this discourse may be found in the writings of feminists concerned to reclaim and revalue 'traditionally feminine' attributes (Merchant, 1980, 1983; King, 1983). These writers strongly refute the idea that biological sex determines one's capacities, but they bear striking resemblance to those who hold this view in their insistence that fundamentally the only possible path into science for women is the construction of a separate science. Starting from the position that science has been constructed by men and embodies masculinist values, they advocate the construction of a feminist science which embodies 'feminine' values. Women, we are told, are socialized differently from men; they are more caring, work co-operatively rather than competitively, take a global view of issues, are concerned to support each other rather than to gain personal advantage. These attributes are regarded as being better than those of men: they are the values associated with nurturing and building rather than destruction, and in the context of the current environmental movement the idea of living in greater harmony with nature and our fellow human beings is very appealing.

The danger, however, lies in the construction of an 'essential woman'. As Wacjman (1991) points out

> Essentialism, or the assertion of fixed, unified and opposed female and male natures has been subjected to a variety of thorough critiques. The first thing that must be said is that the values being ascribed to women originate in the historical subordination of women. The belief in the unchanging nature of women, and their association with procreation, nurturance, warmth and creativity, lies at the very heart of traditional and oppressive conceptions of womanhood. 'Women value nurturance, warmth and security, or at least we believe we ought to, precisely because of, not in spite of, the meanings culture and social relations of a world where men are more powerful than women' (Segal, 1987, p.4). It is important to see how women came to value nurturance and how nurturance, associated with motherhood, came to be culturally defined as feminine within male-dominated culture. Rather than asserting some inner essence of womanhood as an ahistorical category, we need to recognize the ways in which both 'masculinity' and 'femininity' are socially constructed and are in fact constantly under reconstruction. (p. 9)

The construction of an essential woman ignores the differences of class, ethnicity, race and the myriad other factors which interact with gender to construct a student's identity. An attendant difficulty of this position is the marginalization of those few women who have, despite the odds, managed to remain in the physical sciences. It is somewhat galling to be told, after years of effort to assert one's right to a place in science, that one has sold out to masculinist values, or that one has forfeited one's right to be considered a real woman: both assertions have been made in my hearing, by individuals committed to affirmative action in science classrooms, referring to women who work in the physical sciences.

Secondly, the construction of an essential woman perpetuates a set of gendered dualisms. In constructing an ideal woman in opposition to the unsatisfactory male, one perpetuates the tendency to construct the world as entities in opposition: black and white, bad and good, rational and irrational, masculine and feminine, self and other. This oppositional thinking may act to confirm and continue the processes which established women as 'other' in the first place (Weinrich-Haste, 1986).

Popular mythology constructs images of men and women as opposites, and certain attributes and cognitive styles are, in this scheme, available only to men. Traditional science, it may be argued, draws on the attributes and skills of men, while 'girl-friendly science' values the skills of women. Women and girls remain locked into traditional and stereotypical versions of what it is to be female. Men and boys are equally locked into the stereotypical version of what it is to be male, and locked away from the nurturing, co-operative, global approach we now value. Girls are different from boys, so girls' science is different from boys' science. It now becomes necessary, however, to demonstrate that girls' science is as good as, although different from, boys' science: a problematic task, if one accepts much of what has been recently written concerning the gendered construction of science (Easlea 1986; Keller 1983, 1985), particularly in view of the power structures which operate throughout science, schooling, and society.

To construct a science for an essential woman is to construct a ghetto. Those of us active in the field have become very wary of asserting that a strategy is better for girls: all too frequently this results in the denigration of the strategy. Real men will continue to do real science: we keep a special science for girls because they cannot cope.

Stage 4: Complete Relativism

The fourth stage is identified by Keller (1986, 1989) as one of infinite plasticity with respect to gender, and complete relativism with respect to science. Each person is an individual. There are not two genders, but many possible shades of masculinity or femininity. There is no longer one science, or even two, but many sciences, each constructed by an individual to suit his or her needs, and each equally true from the perspective of that individual. Each perspective is as good as another. But how, then, does one deal with the role of the institution of Science, which acts to select that which constitutes the best science? How does one counter the expectations we have of girls which are based on nothing more than the fact that they are girls, and which profoundly influence their socialization?

Keller (1986) defines science as "the name we give to a set of practices and a body of knowledge delineated by a community - constrained although certainly not contained by the exigencies of logical proof and experimental verification" (p. 172). Consider the implications of this definition. The set of practices and body of knowledge which constitute science are delineated by a community. The community of scientists decides what is proper science. Many of the expectations are unwritten, implicit, and are acquired as part of the process whereby one becomes a scientist. (See Keller, 1992, for further discussion of this point.) It is this community which shapes science, through the processes of peer review and the choice of projects to fund . This is one reason why science, although it may be socially constructed, is not completely relative: science is what scientists do, and Science, the institution, decides who may be named 'scientist'.

The second feature which keeps science from complete relativism is also to be found in Keller's definition of science. It is that body of knowledge constrained by the exigencies of experimental verification. At some stage the predictions of science are tested, and confirmed or shown to be inaccurate. True, this process may involve a convoluted chain of theoretical links, so that one wonders what exactly is being determined, but at some stage there is an appeal to some external reality. To quote again from Keller (1989):

> Does, indeed, any meaning of the term [science] remain? If it does, that meaning must derive from the shared commitment of scientists to the pursuit of a maximally reliable (even if not faithful) representation of nature, under the equally shared assumption that, however elusive, there is only one nature. (p. 41)

The constructions which are gender and science are social constructions and the processes of socialization of men, women, and scientists ensure the continuation of these categories (Keller, 1989). These are issues which deal with power relationships within society, and it is not simple to disentangle the threads which enmesh the construction of gender and the construction of science by society. Because of the role of a community in defining science, and in the constraint of experimental proof, science avoids the slide into extreme relativism. In a similar manner, society acts to construct gender, by concensus, from the raw material which is biological sex. Although individuals may display characteristics which lie along a continuum, yet our expectations of them are polarized, often along an axis with male behaviour at one end and female at the other. It is difficult at present to envisage what will constitute the equivalent of experimental verification for gender.

CONCLUSION

Keller (1989) asserts that recognition of the social processes of the construction of science is crucial in the choice of a model to describe and explain the relations between men, women, nature and science. My experience in schools leads me to hypothesize that although science teachers are willing and able to recognise gender as socially constructed (although the extent to which they are willing to challenge the construct varies) they largely regard science as a true mirror of nature. If this is so, then there are implications for the teaching of physics in schools, to both girls and boys, and for the likely success of intervention projects designed to encourage young women to study physics. This is the area which I am presently exploring.

To return to the four stages identified in this paper: they represent extreme positions, and although they provide stability of a sort, it is likely that it will be the middle ground, the balance point, which will prove most productive for the future. To complete the reference from Allard with which I started this paper,

> We tread the tightrope attempting to deconstruct the sex/gender assumptions which operate in our culture and through the curriculum, attempting to empower students with the range of skills, the body of knowledge, the values which will enable them to understand and make sense of the sex/gender system, to reconsider – and reconstruct – the notions of power (Allard, 1992, p. 14).

Allard's vision of a tightrope implies a balance point between two extremes. For educators in science, the balancing act is more difficult because there is a choice of four extreme positions (stages) between which the tightropes are strung. If we are to honestly empower our students, this must involve acknowledgement and careful consideration not only of the sex/gender system, but also the science/nature one.

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CHEMICAL APATHY OR HYSTERIA: WHAT ROLE FOR EDUCATION?

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ABSTRACT

Emotional responses from local community groups to the establishment of new industrial activities, involving toxic chemicals, are common. The need for more public education about chemical hazards has often been stated. In the eastern suburbs of Melbourne, PCBs have been stored since 1985, pending their destruction. Council approval for the siting of a pilot plant for their treatment recently caused controversy. This paper presents an analysis of the situation, defines the knowledge needed by ordinary people to participate effectively and rationally in decision making and discusses the acquisition of that knowledge in a community setting. It is not the intention of the author to discuss the contribution that could be made through formal secondary education.

INTRODUCTION

The siting of a pilot treatment plant for the destruction of PCB waste caused a recent controversy in the outer eastern suburbs of Melbourne. The fate of PCB wastes from electrical transformers and capacitors has been a topic of debate for many years (Beder, 1991; Raloff, 1987; Sworzyn & Ackerman, 1982). The disposal of PCB and other scheduled wastes, formerly called intractable wastes, has been a long term problem for Australia. In the past PCB wastes have been burnt in high temperature incinerators in Europe or at sea in a specially equipped vessel. However, most PCB waste is stored in containers awaiting destruction within Australia. The option of exporting this waste is no longer acceptable to the global community (Dayton, 1989).

In 1992, a media release from the Environmental Protection Authority (EPA), described the potential use of "a new technology for disposing of waste containing toxic polychlorinated biphenyls (PCBs)" and the application of a Bayswater company to carry out trials (Age, 13 & 14 September). The local council were alerted to a possible change in the approved use of the company's premises by the press release, and insisted on the proper planning steps being taken. Following receipt of the company's application, the council notified the adjoining property owners by certified mail that the application had been made. Signs were erected at the site for a two week period and a newspaper advertisement was placed the month before the application was considered and approved by council. The application was subject to a hearing by the Administrative Appeals Tribunal because two objections were received. The local community were not consulted in the decision-making process and as their awareness grew they organised themselves to oppose the company's proposed operations.

Community opposition to industrial activities involving toxic chemicals is common in today's society (Brotherton, 1990). The controversy that developed forms a case study which is used to explore the following questions:

What is known about PCBs by scientists?
What is known about PCBs by people in the community?
How accessible is the scientific information to the community?
What are the problems a community has in coming to a decision?

Discussion of these questions will show that the community is neither apathetic nor hysterical but that they lack information with which to make informed decisions.

SCIENTIFIC AND MEDICAL KNOWLEDGE

The potential routes of exposure to polychlorinated biphenyls (PCBs) for the local residents are by ingesting contaminated food or soil particles and by breathing in fumes containing unburnt PCBs in the event of a fire. Although environmental contamination is unlikely the persistence of PCBs and the consequences of peoples' exposure in the past are a cause for concern.

PCBs are stable organochlorine compounds derived from the chlorination of biphenyls. They are fire resistant, good thermal conductors and lubricants (Wassermann & Wassermann, 1983). The distribution of PCBs within the environment has become widespread through a variety of means including accidental leakage and spillage, incomplete destruction during combustion and disposal of sewage sludge (Food surveillance paper No. 13, 1989). Once within the environment, the stability of the PCB molecule leads to long term contamination as they resist decomposition. The persistence of PCBs combined with their fat solubility also leads to bioaccumulation in the food chain (Travis & Arms, 1987).

Small amounts of PCBs have become incorporated in the human diet from birth (Arena & Drew, 1986, Food surveillance paper No. 13, 1989). The effect of long term exposure to low levels of PCBs on people depends upon the amount of PCBs that have accumulated in body tissue. Very low levels (2.3ppb blood; 0.08ppm fat) have no observable effects. However, increased PCB levels (11ppb blood; 0.4ppm fat) may produce subtle symptoms, such as, fatigue, nervousness, joint pain and impaired memory (Schnare & Katzman, 1989).

Exposure to higher levels (90ppb blood; 25ppm fat) can produce immune dysfunction. Extended occupational exposure may lead to eye irritation, abdominal pain, skin disorders and deformity of the nails Animals exposed to PCBs have developed liver tumours, lymphomas, leukaemias and carcinomas of the intestinal tract (Schnare & Katzman, 1989; Wassermann & Wassermann, 1983). Worksafe Australia has classified PCBs as an established cancer-causing substance in animals (Independent Panel on Intractable Waste, 1992). In humans, PCBs have been linked with incidents of melanoma among workers who used them as flame retardants and plasticisers in the chemical industry (Simonato & Saracci, 1983).

Contamination of food has led to large numbers of people being accidentally poisoned by PCBs. In Taiwan, more than 2000 people were exposed to contaminated cooking oil between December 1978 and October 1979, when the oil was removed from the market. For more than six years following this incident, children were born with abnormalities of the ectodermal tissue, such as nail deformities and pigmentation. Lower birth weights and developmental delay also occurred. This incident followed a similar outbreak in Japan in 1968. (Arena & Drew, 1986; Rogan, 1986). The source of PCB contamination in food has generally been leakage from electrical heating / cooling systems and this use of PCBs has been discontinued.

Increased understanding of the persistence of PCBs in the environment and of the effects on the health of people and the environment has led to controls being placed on the use and disposal of PCBs (Sworzyn & Ackerman, 1982). Within Australia, individual states are responsible for controlling the use and disposal of PCBs (Independent Panel on Intractable Wastes, 1992). States will be required to operate within National Guidelines currently being prepared which include the recommendation that no central high temperature incineration facility will be built in Australia (Scheduled Waste Working Group, Report to ANZECC, May 1993).

Base Catalysed Dechlorination (BCD) is one of a range of alternative technologies being considered for the destruction of PCB containing wastes. In this process the waste is heated to about 350°C with caustic soda, a hydrogen donor and sugar in a closed reaction vessel. The chlorine atoms from the PCB molecule are replaced by hydrogen (Independent panel on the Destruction of Intractable Wastes, 1992).

The current owners of the Bayswater site, BCD Technologies Pty. Ltd., have designed a mobile unit for the destruction of PCBs at the sites where they are stored. Within the unit 1000L batches of contaminated oils would be treated using the BCD process. The unit is designed as a closed system so that no emissions would be discharged to the environment during its operation. Safety features incorporated into the design include automatic monitoring and shutdown devices, as well as foam fire extinguishing equipment (Sworzyn & Ackerman, 1982).

The company would be trying out the operation of the unit for the first time at the Bayswater site and it would operate under the close scrutiny of the Victorian EPA (City of Croydon, 1993, Public information package).

COMMUNITY KNOWLEDGE

The site at the centre of the controversy has been used for the breaking down of electrical equipment and the collection and storage of PCBs since 1985. The residential areas nearest the site were not developed when approval was given by council for this use. There are now approximately 2800 people living within a 1km radius of the site and a housing estate only 400 metres away (Maher, 1993, correspondence). It is unlikely that the residents knew how the site was being used prior to the development of the controversy or that they were aware of the proposed change of use.

Community awareness of plans to operate the pilot treatment plant at the site increased rapidly. A residents' action group began to oppose the proposed new use of the site indicating that it was lack of knowledge rather than apathy that contributed to the residents failure to lodge an objection prior to council approving the application (City of Croydon, 1993, Public information package).

The activities of the residents' action group demonstrated that the community knew it had to act collectively to oppose the pilot treatment plant. A petition signed by 700 people was presented to the mayor at a council meeting in an attempt to have the decision reversed (Croydon Mail, Tuesday 30 March, 1993). Legal representation from the Environmental Defenders Office of the Community Legal Aid Service was obtained to help participate in the appeal process.

The community also knew that if there was an accident contaminating their home sites there would be a detrimental effect on the value of their properties. As one resident stated:

> If something does go wrong we won't be able to sell our homes and move. No-one will want them.

Many questions were asked at a public meeting indicating that the community did not have a uniform understanding of the issue and wished to know more. The following questions indicate the community's concern for its safety and well being:

"How dangerous are the stored materials?"
"How safe is the system?"
"What is the council going to do if there is a fire? How do we get out? Where do we go?"

ACCESSIBILITY OF INFORMATION

There is a large amount of information about PCBs. Information can be found in print, on video, electronically stored on compact discs and by contacting people, for example, government agencies such as the EPA, where there is a responsibility for public education.

Initially information provided by the council, about the application for a planning permit, was not readily accessible to the residents. The placarding of the site was not visible from the main road by residents and the media advertisement relied on the assumption that all residents read the local newspaper. Where the adjoining property owners were notified by certified mail objections were received. Information would have been more accessible if a leaflet had been distributed to each resident.

Print media played a vital role in the presentation of information to the community. The first information about plans for the Bayswater site reached the local council through the Age newspaper article on 13 September 1992. It was echoed in the local newspaper soon after. The two local newspapers provided a vehicle for the presentation of information to the community as the controversy developed. A range of views from the different parties involved were presented.

The Croydon Mail (23 March 1993), printed an article that provided a clear overview of the PCB issue. Information about the history of PCBs in Australia, their uses and persistence within the environment was provided. The BCD process and the experimental nature of the pilot treatment plant was described as well as the health effects and the uncertainty of how toxic PCBs are. An attempt was made to relate scientific information to everyday aspects of life as can be seen from the first sentence of the article:

> Imagine a giant percolator filled with caustic soda, sugar and polychlorinated biphenyls (PCBs).

Less scientific information was presented as the controversy developed further. The newspapers did not exclude anyone involved from media coverage but did tend to sensationalise the issue by reporting the emotional responses of people, for example,

> North Bayswater and Croydon Residents Action Group spokeswoman Janine Hancock said residents who attended Monday night's protest meeting were 'furious' with Croydon Council's mayor Peter Tredrea for asking them if they were from "rent-a-crowd". (The Croydon Mail, Tuesday, 30 March)

The newspapers gave the information needed for residents to come to an informed decision but the possible bias of the party providing the information still had to be interpreted by the community.

The local council also acted to provide residents with information. Residents were invited by their council to peruse files containing all the information relating to the Bayswater site. Public meetings were also organised to provide further information and the opportunity for questions to be answered by speakers with expertise related to the disposal of scheduled wastes.

A public information package, providing much valuable information, was prepared and distributed by council. The history of the site, the planning process and the process to be used in the pilot treatment plant was described. Correspondence between the council, the EPA, BCD Technologies Pty. Ltd. and another company expressing concerns about the BCD process were also included. Various other pieces of information, such as, newspaper articles, USA patent applications and scientific papers were also attached to the package. Not all relevant information was included. For example, there was no information about potential environmental and health problems.

Some useful sources of information were located in the community's library. The book *Hazards at work: Health safety and welfare in the Australian workplace* specifically discusses PCB contamination following a fire (Booth et al., 1990). The *New Scientist* is found in the journal collection at the library. In it numerous articles have appeared regularly in recent years describing technologies for the destruction of PCBs, as well as, health effects for animals and people (Park, 1991; Charles, 1991; Beder, 1991).

The development of industry in the western suburbs of Melbourne together with conflict that arises between the community, government and industry during the planning process is documented in the video *In the shadow of the chimney*. The visual images and the interviews with residents provide a personal view which can be readily identified with. The re-enactment by residents of the hearing enables viewers to imagine themselves as part of the process and is valuable preparation for being involved in a similar situation.

PROBLEMS FACING THE COMMUNITY

Lack of consultation with residents in the early stages of the planning process and the speed with which decisions were made quickly led to conflict between the local community and those promoting the trialing of the pilot treatment plant. They had been forced into an adversarial position by being excluded from the early stages of the planning process. Large formal meetings supported the adversarial atmosphere that inflamed the situation.

The meetings provided residents with the opportunity to express their concerns and acquire information by questioning people with appropriate expertise. Koker & Thier (1990) state the importance of knowing how to ask pertinent questions. The answers to the ten questions below would elicit information to develop an understanding of the problem.

- What are PCBs?
- Why are they on that site?
- How could PCBs escape from that site?
- Would I be exposed?
- What effects could exposure to PCBs have on my health?
- What amount of PCBs would cause these effects?
- What possible accidents might occur during the operation of the pilot treatment plant?
- What plans have been made to safeguard people in the community in the case of an accident?
- What is the best way for PCBs to be destroyed?
- Where is the best place for PCBs to be destroyed?

Asking questions of local officials is also an important way of assisting with planning. For example, "Do they know what toxic substances are generated, used, stored in or transported through the community?" (Cutter, 1987)

The information that would answer the above questions comes from many sources. The community needs to clearly identify the institutions that have undertaken the research. The differing interests of these institutions which might contribute to bias, as discussed by Cross and Price (1992), need to be considered.

The uncertainty of scientific findings and the lack of human data relating to the safety of chemicals can be confusing for the public and hinder the development of a broad understanding. Safe levels of exposure for the community are calculated from data collected in studies of the effects of particular chemical substances on cells, microbes and animals. The sensitivity of different animals varies and so the effects of a particular chemical, at a given dose, can be greater than or less than that predicted for humans. The simultaneous exposure to different chemicals occurring in everyday may also produce a greater or lesser harm (Duffus, 1980). There is also little information available about the effects of long-term low level exposures to chemical substances on peoples' health (Deshler, 1990; Schnare & Katzman, 1989). The strengths and limitations of scientific data need to be understood by people in the community (Deshler, 1990; Koker & Thier, 1990).

Scientific information can be accessed selectively to support the presentation of different sides of the issue. In this case, the company argued that the process was safe based upon the success of the trials it had conducted and the technical controls included in the construction of the unit. This was countered with the argument that the unit had not been operated for 1000L batches therefore its safety was not established.

Adverse community responses to the disposal of toxic waste in the past should have alerted the council to the need for time to be spent informing the local community and consulting with them prior to the approval of the application so that their concerns could be addressed and trust could be built. The council needed to recognise that people do not readily accept risks that they have not chosen for themselves and that they lack faith in government and industry.

Inclusion of these groups in the planning process could curb unrealistic local expectations that planning will eliminate all possibility of accidents. Rather, it may clarify that while some risks remain, the joint planning effort can minimise dangers. This result could not only restore faith in the planning effort, but also satisfy communities and workers that they are participating in making decisions concerning risk acceptance or rejection with full knowledge of the available facts. (Abrams & Ward, 1990)

The experts needed to get among the community discussing the issue with people at small informal meetings (Chess & Salomone, 1992). The community's lack of faith in government and industry and the feeling that they are going to be ignored or mistreated (Chess & Salomone, 1992) needed to be addressed by giving a high priority to working co-operatively with groups of residents to address their concerns. They were afraid that they would become the powerless participants in an environmental disaster as has occurred in other communities (Levine, 1982). As the peoples' advocate from the Environmental Defenders Office stated at a public meeting, "Now we are dealing with fear. The public confidence must be won back."

THE ROLE OF EDUCATION

The role of education is to facilitate action based upon informed decisions. Although community education has existed for hundreds of years it is still not clearly defined (Rennie, 1990). The need for lifelong education that is not only judged according to the component of knowledge but that also values the personal development of the individual has been identified by UNESCO (Lengrand, 1970). Models for environmental education combine both the acquisition of knowledge and a personal component in the development of responsible environmental (citizenship) behaviour and are applicable to the needs of the community involved in this controversy (Hungerford & Volk, 1990).

Knowledge of the issue and of action strategies are needed to make sound decisions regarding a solution to the issue. However the presentation of knowledge is problematic, particularly in the area of risk communication where different people process risk differently (Desvouges & Smith, 1989). Personal factors together with action skills are interrelated with the knowledge to produce citizenship behaviour (Hungerford & Volk, 1990).

A possible model that would foster the interaction between the individual's personal beliefs, the development of knowledge, skills and commitment to action is based upon the writings of the Brazilian adult educator Paulo Friere. The Adult Learning Project in Scotland was started in 1977 by a small group of women supported by a neighbourhood community worker and a community education worker (Kirkwood & Kirkwood, 1989).

The learning occurs in a non-threatening environment, such as local kindergartens, schools or community centres, and is structured over an extended period of time. The leaders take on roles of organisers and facilitators of the learning group's investigation with the members of the group becoming increasingly responsible for their own learning. Learners are supported as they develop a broad understanding of the problem being considered, reflect and take action upon it.

The learners explore what they already know and define what they want to find out. Questions are asked, information is gathered or provided by people with expertise who become integrated within the group acting as resource people rather than guest speakers. Discussion and interpretation helps the learners to construct patterns of meaning. Reflection and action are an important part of the learning program.

It may be that through this process the delaying or halting of new projects would lead to more equitable outcomes. The parties involved in this controversy might have begun to work together to consider options such as compensation to the local community for the siting of this unwanted facility as has occurred in the USA (Himmelberger, Ratick & White, 1991).

CONCLUSION

The case studied and described in the paper demonstrates that there is information to support community participation in the planning process and that the operation of new commercial activities can be delayed. It also illustrates the fear produced within the local community that motivates them to actively oppose new developments in their neighbourhood. These fears and concerns need to be addressed to facilitate the development of a broad understanding of controversial new developments. It is also important that the community's questions are answered and that they are consulted before decisions affecting their potential well-being are made.

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STUDENTS' UNDERSTANDING OF CONCEPTS RELATED TO PLANT GROWTH

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ABSTRACT

This paper reports on an investigation into students' understanding of the concept of plant growth. There are three aspects to the research. First, responses of Australian primary students to questions concerning plant growth are compared with those identified in British research (Russell & Watt, 1990). Second, the answers of secondary students, Year 7 - Year 12, to questions concerning plant growth were analysed and common categories of responses were identified. Finally, the response categories were considered within the framework offered by the SOLO Taxonomy of Biggs and Collis (1982, 1991). In particular, interest was focused on whether the findings of an earlier study (Levins, 1992) in which cycles of development in the understandings of the concept of evaporation were established, might be observed in the concept of plant growth.

INTRODUCTION

Many researchers have investigated the process of acceptance and consequent development of scientific ideas into children's cognitive frameworks (e.g. Osborne & Freyberg, 1985). Much of the work in this area has been concentrated in the primary school. One team of researchers, working in this field, is grouped under the project name of Primary SPACE (Science Processes and Concept Exploration). Scientific concepts, such as evaporation and condensation, light, sound, electricity, materials, and growth, have been considered by this project team, and a series of reports on their findings published. The results of this work have been used to develop teaching/learning materials for teachers and students. These are currently being tested in schools in England.

One of the concepts that the Primary SPACE project team investigated was that of 'growth' (Russell & Watt, 1990). Their study involved students from infant school to junior secondary (5-11 years). The researchers used a pre-test/post-test design to explore the tenacity and development of children's intuitive ideas about the growth of both plants and animals. As a benchmark, they defined the idea of 'growth' as consisting of a compilation of the following list of concepts:

- Everything which is living has the ability to grow.
- Growth requires energy which is provided by food:
    - plants make their own food from raw materials,
    - animals eat ready-made food.
- The food materials are transformed and incorporated into structural material.
- The mass, volume and shape of the organism change as a result of growth.
- Each organism has an optimum size to which it grows (in favourable conditions).
- Growth takes time to happen, and this time varies with conditions and between organisms (Russell & Watt, 1990).

Their study used these 'accepted' scientific explanations about growth and compared them with students' ideas after they had been introduced to ideas by their classroom teachers about animal and plant growth (this being the form of intervention used in their study). The findings of their research concerning plant growth can be summarised by the following points:

- As the age of the student increased, so too, did their ability to recognise the fact that more environmental conditions were necessary for the growth of the plant.
- Many students saw growth of a plant, as the 'unfolding' of material, rather than the production of new material.
- The necessary environmental conditions were seen as external facilitators for plant growth, rather than as an integral part.
- Very few students recognised light (sun) as being a component of the growth of the plant.

These results represent an important insight into how young children view 'growth'. However, more needs to be known about the development of the understandings if the results of such research are to be widely applicable in the classroom. In particular, it would seem valuable that more data be collected on the development of:

- intuitive scientific ideas held by young children; and
- the abstraction of these scientific ideas.

One possible way to provide a model to describe such data has already been outlined by Levins (1992). In that study she explored students' understanding of the concept of evaporation using the SOLO Taxonomy of Biggs and Collis (1982, 1991) as the underpinning framework. The key finding of this work was the identification of two cycles of development. The first involved 'real world' descriptions of scientific phenomena and the second centred on the processes responsible for the realisation of these phenomena. It would be valuable to investigate if this finding was generalisable to other scientific concepts, such as plant growth.

In order to provide a focus for this current investigation three research questions were developed:

- How do the responses concerning the concept of plant growth given by young children in an Australian school compare with those offered by the children studied in the SPACE project?
- Is it possible to classify a large number of secondary students' written responses to five questions concerning the scientific concept of plant growth, into categories and, if so, what are the characteristics of the groupings?
- Does the categorisation reflect the findings of Levins (1992), which can be incorporated into the SOLO Taxonomy (Biggs & Collis, 1982)?

THE STUDY

To investigate ideas associated with plant growth, a set of five questions was developed around a reference diagram (see Fig. 1). A specific diagram was provided so that both the younger and older students had the same diagrammatical configuration from which to work. It was felt that the diagram would assist in directing students' ideas while, at the same time, allowing students to answer the questions according to their individual meanings of the word 'growth'.

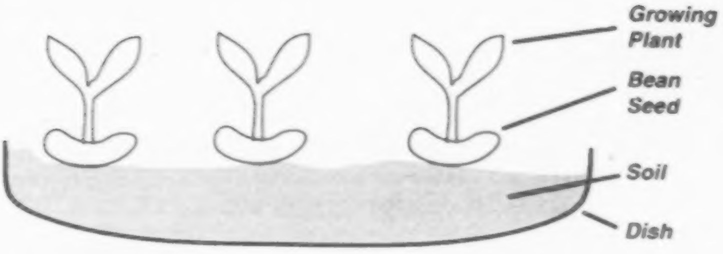

Fig. 1. Reference diagram for the investigation of ideas associated with plant growth

The five questions used in the study were:

1. If you were asked to give an explanation suitable for a Science dictionary, how would you explain plant growth?
2. How would you know if the plants were growing?
3. What 'things' would plants need to take from the surroundings to help them grow?
4. In as much detail as you can, explain how the necessary 'things' that the plants take from the surroundings help the plants to grow?
5. Explain how photosynthesis is a necessary part of a plant's growth.

Several important features were built into the set of questions. The emphasis was on students providing their personal views/ideas about the questions rather than learnt responses. In particular, questions 1 and 2 attempted to establish this context for the answers. The questions were also designed to elicit 'open' and 'closed' responses. Questions 1 and 5 were 'open' in nature and therefore provided the opportunity for students to give as much information as they could. Questions 2, 3 and 4 were 'closed' in nature. Here, the questions were designed to prompt a sequential development of the responses from the students.

Two samples of students from one school were involved in the study. In selecting the samples care was taken, given the constraints of student/class availability, to represent as broad a range of abilities as possible. The first sample was drawn from the primary school and comprised seven primary students, three girls and four boys, aged between 9 and 11 years. This age group was chosen for two reasons. Firstly, it was the same as used by Russell and Watt and secondly, the students would be beginning to meet formal science concepts in school (i.e., when students are able to use and show understandings of scientific language, when discussing everyday events). The seven students were interviewed for about 20 minutes each. The interview format was not rigid and took the form of a one to one discussion. However, the questions described above were interspersed throughout the interview. The young students were urged to make drawings, if they felt this might help them explain their understandings of plant growth. The conversations were taped.

The second sample comprised 201 secondary students spread across Year 7 to Year 12. The numbers in each year was as follows: 56 in Year 7, 62 in Year 8, 15 in Year 9, 46 in Year 10 and 22 in Year 12. The reason this group was chosen was to allow for a broader overview of students' concepts of 'growth' and to extend the work of Russell and Watt. The students were provided with the diagram and asked to respond in writing to each of the five questions in turn. There was ample space provided for a full written response. The scripts were retained for analysis.

RESULTS

Research Question 1

> How do the responses concerning the concept of plant growth given by young children in an Australian school compare with those offered by the children studied in the SPACE project?

The primary students relied heavily on explanations using everyday occurrences from their own real world. Their discussions, in most cases, centred around their own gardens. Five features were consistent across all seven interview transcripts:

1. The students concentrated on water and soil as the necessary conditions for growth. Soil was seen as important for structural support and sometimes as a provider of food. The students all spoke of watering their own gardens at home. They recognised that watering the plants kept them alive. They constructed their own understanding of the necessity for water in the process of plant life from their own experiences. They did not identify growth as being a property of life. Their discourses were many-faceted and showed no direction or linkages from one idea to the next.

2. Only one student mentioned the sun. He felt the sun was important to keep the plant warm! None of the students differentiated between heat, light and sun as being an integral part of a plant growing. None of the students showed any understanding of the concept of photosynthesis. One boy, who analysed the word, decided it had something to do with making a photograph.

3. Air, oxygen and carbon dioxide were mentioned by the students volantarily.. When asked for explanations, the students were unable to ascribe any function to these gases. They were unable to disentangle the idea of oxygen and carbon dioxide as being parts of the air, except they were positive that all three gases were important requirements for plant growth. This inability by the students to make linkages between ideas was ascertained by the interviewer by continual probing. This took the form of consistently asking for explanations.

4. Most students could identify that time and increase in size were elements surrounding plant growth. It was interesting to note that every student spoke about plants growing over an infinite period of time. For example, when asked: How long would a plant grow? A typical response would be: "Forever!"

5. The students did not differentiate between germination of seeds and growing of plants. They did, however, speak of the "unfolding" of the plant, which would suggest a reliance on their memory and understanding of experiments involving germination of seeds at home or at school. Russell and Watt found the same imagery used by their sample of students (p. 89). Many of the above features were also evident in the findings outlined in the research report written by the SPACE project team.

When the data from the primary student interviews in this study were compared to the compilations of scientific concepts surrounding the idea of 'growth' given by Russell and Watt (quoted earlier in this paper), the following became evident:

- Young children's scientific ideas of growth differs in many aspects from the commonly held scientific conceptual view.
- The children's explanations are seen by them as valid, when constructed from their experiences.

How then did the written responses offered by the secondary students differ from those descriptive understandings given above by primary students? The primary students centred their conceptual understandings around their own experiences of reality as they perceived it. Their explanations were usually in the form of a story and highly image-laden. The younger students gave little or no regard to cause and effect. The only relationship they mentioned was: if a plant was watered, it would remain living. Since the students 'went off' on many tacks when discussing an idea, no apparent linkages appeared, between the environmental precursors and the resultant growth of the plant. The interviewer had to be aware not to impose the causal relationships between what the students said and what was known to be a scientific fact, i.e., water is one of the necessary factors that results in the growth of a plant. As the age of the students increased, so too, did their ability to relate their understandings in more conceptual terms. There was a noticeable shift away from egocentric descriptions of events to a more objective analysis of events. This shift occurred as the students' acceptance of the scientific explanation of events increased. They began to recognise more causal relationships between environmental elements and the resultant growth of the plant. All the above mentioned characteristics shown by the younger students, reflect the description of the ikonic mode (Collis & Romberg, 1992). This mode seems to be a necessary intellectual support system for the students. They are then able to move into and operate within the concrete symbolic mode. The differences between the two modes can be highlighted by the use of data collected to answer the second research question.

Research Question 2 (Secondary Students: Categorisation)

> Is it possible to classify a large number of secondary students' written responses to five questions concerning the scientific concept of plant growth, into categories and, if so, what are the characteristics of the groupings?

The results of the analysis of the students' responses did result in a number of discrete groupings. The categories provided a broad perspective of the variety of understandings held by students of varying abilities in the school years 7-12. The following summary, which explains some of the ideas underlying each category and provides examples of typical student answers, illustrates the richness in the data:

Category A: non-codeable Responses which were placed in this category were those in which the student denied any understanding of the question, answered tautologically or refused to respond. For example, to the instruction, "Explain how photosynthesis is a necessary part of plant growth", typical responses were: "So we live."(Year 7); "...if it didn't have it, we would die." (Year 9).

Category B: one feature described In this category, students were capable of recalling only one point to answer the question. For example, one Year 9 student wrote, "...how much a plant would grow in a certain period of time". This statement indicates that the student understands that time is a necessary feature of plant growth. Another response focuses on the feature of size e.g. "...is a measurement that a plant would show" (Year 10).

Category C: more than one feature described Responses were placed in this category if the student described two or more features, which would be necessary for a plant to grow. "What 'things' would the plants need to take from the surroundings so that they could grow?" Two examples of such responses to the question are, "...H_2O, CO_2 and soil" (Year 8) and "Water, soil, sun" (Year 7).

Category D: overview of ideas leading to a single process The students were able to draw conclusions and make generalisations. They could make linkages and form relationships between features necessary in the growth 'process'. For example: Given the instruction "In as much detail as you can, explain how the necessary 'things' that the plant takes from the surroundings help the plant to grow.", typical responses were: "...through photosynthesis, nutrients and water, are converted to starch and then cellulose to be used as building blocks for the plant" (Year 10); "...they use photosynthesis, which means the supply of light, soil and air, so the plant can make its own food" (Year 7).

Categories E, F, G: process-oriented The student responses allocated to these categories reflected the idea that the growth of a plant required chemical processes inside the plant's cellular structure. Although all three categories were process-oriented, the differences in the level of the understanding of the processes involved, warranted a separation of responses into three separate categories.

Category E: process-oriented This category reflects an understanding of the process of photosynthesis required for growth, but no linkages are made between the reactants in the process and the products which ultimately provide the materials necessary for plant growth. For example, when asked, "If you were asked to give an explanation suitable for a Science dictionary, how would you explain plant growth?", a typical response at this level was: "...the plant will need water and sun light to grow. As it grows it will take in CO_2. The leaf is where the plant makes its own food using photosynthesis" (Year 7).

Category F: process-oriented Responses in this category reflected on overall understanding of the photosynthetic process and intermediate processes involved. To illustrate this, a typical response from a Year 10 student follows: "Plant growth is the way a plant creates more of itself by absorbing external matter. Plants achieve this by using the process of photosynthesis, whereby chlorophyll in the leaves, nutrients and water from the soil, and CO_2 are combined by energy from the sun to form simple sugars that the plant uses to build itself".

Category G: process-oriented The student responses (there were very few) which were coded into this category, showed a far greater degree of understanding than any responses classified in any other category. The responses in this category reflect the fact that the students were able to understand the underlying processes (photosynthesis and cellular respiration) necessary for plant growth, i.e. they are able to deal with abstract ideas and relate them to the concrete world. Piaget would have referred to this ability as 'conservation'. One example follows: "Plants convert; $CO_2 + H_2O + \text{Energy} \rightarrow \text{glucose} + O_2$. This is very important because plants waste product is O_2 and this is essential for animals to breathe. The glucose which is produced by the plant is often stored as starch, however, when the plant uses glucose (respiration), this allows the cells to live, grow and reproduce" (Year 12). In this response the student has shown a fuller understanding of plant growth. With the inclusion of the process of respiration in the answer, the student has drawn on information from outside the context of the question to explain the concept of plant growth more fully.

Since the responses can be classified into discrete categories, research question 3 can be addressed.

Research Question 3

> Does the categorisation reflect the findings of Levins (1992), which can be incorporated into the SOLO Taxonomy (Biggs & Collis, 1982, 1991)?

Secondary students and SOLO Taxonomy. A comparison of the verbal responses of the primary students and the written responses of their secondary counterparts shows a development in understanding in the scientific conceptual explanation. There is an obvious shift from experience-based (anecdotal) to conceptual explanations of scientific phenomena, such as plant growth. The characteristics shown by the younger primary students reflect the description of the ikonic mode (Collis & Romberg, 1992). This mode seems to be a necessary intellectual support system for the students. They are then able to move into and operate within the concrete symbolic mode, within the terms of the SOLO Taxonomy.

The following discussion considers the categories A–G in the light of the SOLO Taxonomy descriptions (refer Collis & Biggs, 1991).

Category A. The students' responses are not able to be coded. This fact may reflect the fact that the students were not yet able to give explanations other than their own constructed alternative ideas i.e. Prestructural.

Category B. The students have focused on one feature when answering the question, e.g., they focused on soil or water or size. In terms of the SOLO Taxonomy these single, discrete, concrete, reality-based descriptions would be referred to as unistructural.
Category C. This level of response was characterised by descriptions containing more than one feature, without any observed relationships between the features. This is typical of a multistructural response in terms of the SOLO Taxonomy.
Category D. The responses in this category included descriptions of photosynthesis, by relating growth to the process. The recognition that the process of photosynthesis is a necessary part of growth, requires the student to have on overview of the scientific term 'growth'. This category would be equivalent to the relational level in the SOLO Taxonomy.
Category E. There are similarities between category E and category C in that more than one description is offered. The important difference is that in category E the description outlined in the responses is process-oriented. The features discussed in this category reflect abstraction of ideas, e.g. the incorporation of CO_2, light energy and water as necessary components. This category (as category C) can be considered to be multistructural with reference to the SOLO Taxonomy.
Category F. The overview of the process of photosynthesis as an integral part of plant growth is recognised as the central issue in the responses placed in this category. Not only is an overview realised but all the integral features are linked, i.e., the reactants, CO_2, H_2O, energy and the products O_2 and glucose. According to the SOLO Taxonomy, it would be considered that the student is responding at the relational level.
Category G. According to the SOLO Taxonomy, responses classified in this category would be put at the formal mode. This mode of operation extends from the concrete symbolic mode. The students are able to go outside the context of the question, and respond with generalisations to explain the scientific phenomena of plant growth, e.g. students can describe not only photosynthesis but cellular respiration being necessary processes for the growth of a plant.

These results, as depicted in Fig. 2, would corroborate the findings outlined previously (Levins, 1992). As suggested in that paper, it appears that a single cycle of levels provides too simplistic a view of the concrete symbolic mode. In this study, as in the investigation of the concept of evaporation, two cycles have presented themselves. There is a shift from reality-based features (in the first cycle) to a discussion of the processes (in the second cycle) involved in describing the concept of growth.

The results from this study support the view that students require the first cycle to build the basic concepts: students react to reality as they perceive it. These foundation ideas underpin

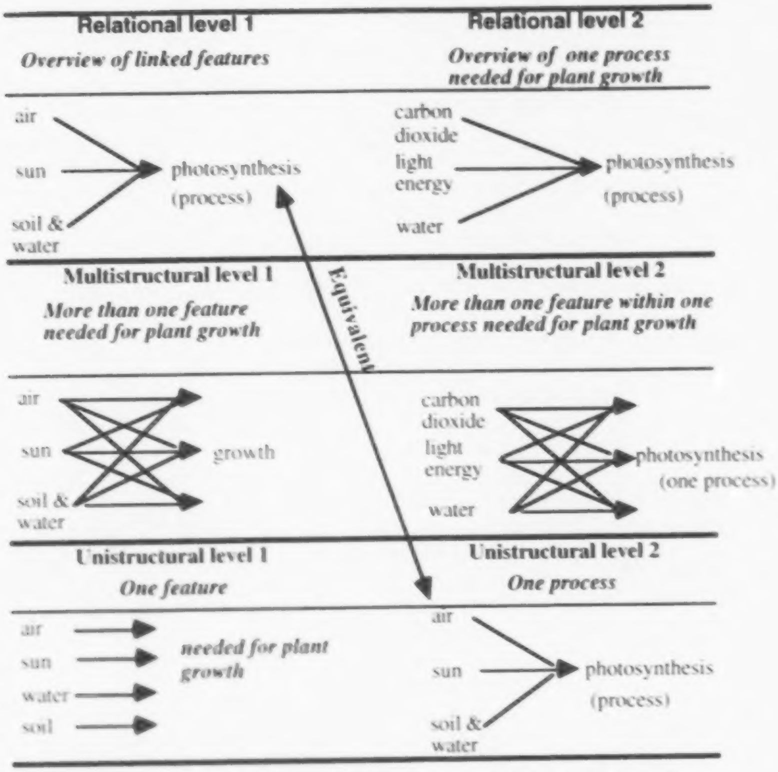
Relational level 1
Overview of linked features
Relational level 2
Overview of one process needed for plant growth
air
sun
soil & water
photosynthesis (process)
carbon dioxide
light energy
water
photosynthesis (process)
Multistructural level 1
More than one feature needed for plant growth
Equivalent
Multistructural level 2
More than one feature within one process needed for plant growth
air
sun
soil & water
growth
carbon dioxide
light energy
water
photosynthesis (one process)
Unistructural level 1
One feature
Unistructural level 2
One process
air
sun
water
soil
needed for plant growth
air
sun
soil & water
photosynthesis (process)

Fig. 2. Two cycles in Concrete Symbolic mode, SOLO Taxonomy

the development of the more demanding cognitive abstraction of ideas into process-orientation. With reference to the findings in this study, the first cycle describes the concrete features involved in plant growth, e.g. water. The second cycle describes how these features are used in the process of plant synthesis. Thius process is only of those necessary for plant growth, but almost exclusively, it was the process mentioned in the responses given by the secondary students in the study.

CONCLUSION

The findings from the primary students in the present study have supported the results obtained by the SPACE project team. All the characteristics shown by the young students in both investigations can be classified within the ikonic mode, as described by Collis and Biggs (1991). The students' understanding of scientific concepts depends heavily on their experiences of reality as they understand it. Causality of events does not influence how the students come to terms with what they experience. The responses given by the students in the secondary school sector could be placed into categories defined by the similarity in type of response and according to characteristic descriptors. These categories do reflect both the level descriptors of the SOLO Taxonomy and the cyclic nature within the concrete symbolic mode as outlined by Levins (1992), concerning the concept of evaporation and by (Biggs & Collis, 1991).

The findings lead into an important area which must be addressed in future investigations. The next stage of this research will address the issue of whether the interface between the ikonic and the concrete symbolic modes can be isolated and described. By collecting data from Year 3 through to Year 8 it is hoped to locate a cyclic pattern in the ikonic mode and some insight hopefully will be achieved in the nature of the mode shift from the ikonic into the concrete symbolic. How then can these findings be effectively translated into classroom strategies for teaching scientific concepts? The development of assessment techniques is already being addressed in some teaching situations; see, for example, Collis and Biggs (1989) and Stanbridge (1990). Not only the assessment of outcomes, but the setting of objectives and outcomes in curricular design could be aided by the implementation of the SOLO Taxonomy. The direction that a curriculum designed using a theoretical framework would give to the classroom teacher is most important. This opens the way to a series of further questions:

- Does this dual cycle of responses occur in answers to questions about other scientific concepts?
- Are there identifiable levels within the student responses in the ikonic mode?
- How do students' intuitive understandings develop into accepted scientific views?
- How can these findings be effectively translated into classroom strategies for teaching scientific concepts?

Answers to these questions would not only help improve the way scientific concepts are taught but also improve the opportunities for students to learn these concepts.

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SCIENCE TEACHERS' VIEWS OF PROFESSIONAL DEVELOPMENT

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ABSTRACT

Seventy-five science teachers from schools across Australia were interviewed in 1991 as part of the Science Education Professional Development Project (SEPD), a Department of Employment, Education and Training (DEET) funded Project of National Significance with a brief to develop a strategy to enhance the professional development of science teachers. At the time of interviewing there was considerable discussion about the implementation of a new classification, the Advanced Skilled Teacher. A major purpose of this Award Restructuring was to offer a career path for classroom teachers. In order to retain good science teachers and to encourage them to continue in the important role of classroom teaching it is crucial to understand and to meet their professional development needs. But what does it mean to develop and grow as a science teacher? What constitutes quality professional development? What do science teachers expect from professional development activities? This paper explores science teachers' expectations in relation to professional development and examines the implications for policy.

INTRODUCTION

The amount of in-service science teachers receive, the value they place on it, and its effects on classroom teaching were some of the issues explored during interviews with science teachers in a variety of schools across Australia. These interviews were conducted as one component of the Science Education Professional Development (SEPD) Project, commissioned by the Commonwealth Department of Employment, Education and Training as part of its Projects of National Significance Program. Its brief was to develop a national strategy for enhancing the professional development of science teachers.

In developing a strategy for professional development, it was important to talk to science teachers to ascertain their views on the quality of what they had experienced, what they wanted in the future, and what they thought the Federal Minister for Education needed to do to enhance the quality of science teaching. Encouraging science teachers to continue in their changing and demanding role as classroom teachers requires an understanding of their career expectations and their professional development needs. If a strategy to enhance the professional development opportunities of science teachers is to be effective, then policy makers need to recognise how the existing work place conditions shape science teachers' views.

METHOD

In order to develop an understanding of science teachers' views and to gain a clearer conception of what needed to be done, seventy-five science teachers from twelve schools in every State and Territory except the Northern Territory were interviewed. These loosely structured interviews which lasted about forty-five minutes, were designed to understand contextual influences on teachers' work through the eyes of science teachers themselves.

Our contact with schools was primarily through system people. We asked for "run-of-the-mill" schools. Ten were government schools, one was a Catholic systemic school and one independent girls' school.

The interviews were transcribed and returned to teachers for correction and comment. Few changes were made by teachers and the results used for this paper are drawn from both groups of teachers (N = 75). The software program Ethnograph was used to code the interviews. A set of thirty codes was used drawn from a range of literature on the context of teachers' work (McLaughlin, Talbert & Bascia, 1990; Johnson, 1990) and the quality of teachers' work life (Louis & Smith, 1991).

WHAT IS PROFESSIONAL DEVELOPMENT?

The Commonwealth Schools Commission (1988) report "Teachers Learning" defines the purpose of professional development as improving the 'educational enterprise' through improved teaching quality and better student outcomes. But how do science teachers understand professional development and what factors affect their views?

Factors affecting teachers' views of professional development

Many science teachers find it difficult to keep up to date with recent developments in both science and science teaching (Loughran & Ingvarson, 1991b). They have little contact with practicing scientists outside schools, they have limited access to developments in science research, they are distant from research in science education, and they are isolated from important sources for their professional knowledge. The reasons for this appear to have more to do with the conditions of employment, than the aspirations or needs of individual teachers.

Low level expectations for the value and usefulness of professional development

Teachers had come to expect little from professional development activities because they had received little from them in the past. For many their expectations were often related to the level of boredom they had experienced. The activities they had attended rarely had a positive impact on their professional development which tended to encourage them to be wary of their choices in the future. Consequently, teachers showed little interest in attending the professional development activities offered.

> I've been to quite a number of them, but half of them are just useless. I walk out of them and just think I've just wasted my time...I've not benefited from this and it's very frustrating...bad speakers and they waffle on about things that you don't need to know, or that you already know, or something that is not helpful to you within the classroom or to teaching. They're out of touch with the students, they're out of touch with teaching, they're out of touch with everything.
>
> I'm appalled at the in-service available. For the last eight years it's been Butcher's Paper in-service....

Many teachers expressed frustration from not getting enough in-service education focused on science content, and the teaching of science content - what Shulman (1987) calls 'pedagogical content knowledge'. Many of the in-service courses offered by systems focused on cross-curricular issues or "process" aspects of science teaching related to system policy objectives. Updating of content and methods for teaching specific science topics appeared to be left increasingly to subject associations and individual science teachers.

As many formal professional development activities for science teachers do not appear to address satisfactorily their pedagogical needs, they tend to look elsewhere for advice and ideas to enhance their pedagogical content knowledge. This may be one reason why science teachers tend to attach more importance to talking informally with colleagues than to externally organised and run professional development activities. They continually spoke of 'learning from colleagues' and 'sharing ideas' as major influences on their professional development.

It is difficult to suggest ways to respond to this situation where many teachers attach more value to the informal, even accidental, interactions with other teachers than planned in-service education. Maybe policy makers have to think much harder about how to restructure the science department as a workplace to capitalise on this collegial learning. This approach will require special training for many heads of department as well as the development of materials, ideas and resources for running useful in-school programs for professional development. The SEPD project has been developing such resources for science departments in an attempt to address this issue, and as a means of valuing teacher's professional knowledge.

It is important that the professional development offered to science teachers is appropriate and relevant as well as being presented in a meaningful way.

Low level requirements for their own professional development needs

In developing a strategy for improving professional development, it was important to ask science teachers what they thought they needed. We frequently put this question in the form, "If the Minister was here, what would you want him to know about your professional development needs and what would you want to tell him about how professional development for you could be improved?"

The striking feature of teachers' responses to questions about their professional development needs was the modesty of their requirements. There was little that would shatter or surprise a Minister. By any objective measure, or in comparison with other occupations, science teachers have limited opportunities to keep up with their field (Loughran & Ingvarson, 1991b). But, an extra half-day or so for a course, a chance to visit another school or factory - these were the limits of most teachers' claims. Responses were couched in global terms related to such things as resources, equipment (amount and use of), content, 'catchy-interest arousing' new experiments, teaching strategies, technology, and, in Victoria, the V.C.E.

Some representative responses were:

> I'd like to polish up a little bit in chemistry.
> I think better facilities.
> I think we need a constant revision of what's [the equipment] in the school. At the last school, every opportunity we got, the lab. assistants used to bring out the equipment and show it to us. Show it to us working.

Not only were their claims for in-service education opportunities modest, they were also vague about what they wanted to get better at. Few of the teachers interviewed were able to articulate clearly their own professional development needs. When we sought more details about their needs or when we made suggestions related to content or teaching strategies, it tended to start them thinking more deeply about their needs. However, many subsequently began to question how real opportunities could be made available. There was not an expectation that their needs would genuinely be met.

It is interesting to speculate on this point. Why did these science teachers have difficulty articulating their professional development needs? Perhaps they have had little practice; how often are they asked to evaluate their needs? Perhaps they possess a hazy idea of what professional development means; maybe few have experienced significant changes in their skills so they don't know what they're missing. Maybe it is because there is no clear direction or model, such as an Advanced Skills Science Teacher (AST), to aim for, with identifiable standards and expectations. Perhaps, if there was a clearer conception of what science teachers are expected to get better at, they would be in an improved position to articulate their professional development needs.

It seems to us as though science teachers were not used to being consulted about their professional development needs. When we spoke with science teachers and probed their views, it was readily apparent that if professional development incorporated a process of determining needs that the outcomes would be much more positive.

A lack of participation in professional development activities

Of all the science teachers interviewed, 77% had attended no more than one day of professional development in science in the previous two years. Only 4% had attended more than three days of professional development in science during the same time period.

With so little time for professional development, keeping in touch with one's area of science must be difficult. It also seems quite unfair to expect science teachers to be up to date with recent innovations with so little support. Table 1 illustrates the number of days attendance at science professional development activities by science teachers in the previous two years and suggests that there are limited opportunities available to assist science teachers to keep up with their field. Perhaps it is not considered important that they keep up? With so little involvement in professional development it is likely that science teachers will come to rely more and more on textbooks and pre-prepared syllabuses. School science may come to be a static body of knowledge rather than the result of a dynamic interaction between the learner and the world of science. It seems an unreasonable expectation that science teachers keep up-to-date in their specialist field when they are not given a real opportunity to be involved in professional development activities.

TABLE 1

NUMBER OF DAYS ATTENDANCE AT SCIENCE PROFESSIONAL DEVELOPMENT ACTIVITIES BY SCIENCE TEACHERS (N=75) IN THE PREVIOUS TWO YEARS.

DAYS	N	%
zero	31	41.3
half	4	5.3
one	23	30.7
two	8	10.7
three	6	8.0
more than three	3	4.0
TOTAL	**75**	**100.0**

> Science teacher: I have been teaching for six years. I have been to one science-related seminar for half a day.
> Interviewer: In that six years, you have had only one day of science in-service?
> Science teacher: Half a day!'

> I think I've probably been to about two in-services. I've just collected things out of books and things like that.

One way of interpreting the data is that it indicates that no-one seriously expects science teachers to keep up with developments in science or science education. Another is that there is no incentive to participate. Teachers receive no salary loading for extending their qualifications in their discipline area. The salary for a teacher with a Ph.D. in their subject is the same as that for a teacher with a pass degree. While there is no guarantee that enhanced qualifications in a subject area will improve the quality of teaching, we have to question the wisdom of a pay system that gives no encouragement at all to upgrading subject knowledge.

The lack of opportunity to participate in professional development could be related to cutbacks in the number of programs offered by impoverished school systems. Science teacher associations and other non-system bodies appear to be increasingly turned to as the main providers of professional development. It would therefore appear as though the onus for professional development is increasingly on the individual rather than the system. We would question whether this lack of investment in professional development is not shortsighted given the effects it has on teacher morale and job satisfaction, and given the accepted need to interest more students in science-based careers.

Science teachers should be in a position that affords them at least a reasonable opportunity to be involved in professional development. Changes in curriculum demand more of teachers. Without adequate professional development support, changes become more demanding and place the emphasis for change solely on the individual teacher.

A lack of time available to attend professional development activities

A reason offered by many science teachers for limited involvement in professional development was lack of time, an inability to 'fit' professional development into their schedule. However, for many teachers, professional development was neither a major school priority, nor something their school could afford, which meant that finding time to attend professional development became increasingly difficult for individuals.

We do not suggest that science teachers used 'time' as an excuse for non-attendance. Most of the science professional development activities that teachers attended were in their own time after school and on weekends. This was due to the limited opportunity they had to attend during school hours and partly because the organisers were teachers themselves and could not be released to offer the programs during the day. When confronted with the realisation that there did not seem to be time for their own professional development, many were unsure of how to remedy the situation. As one respondent said:

> I think we need time where we are actually issued a compulsory invitation to an in-service and you sit down and you get that in-service.

It seems incongruous that, in a profession where learning is the prime focus, the employing body does not appear to foster greater opportunities for this in its workforce. Moreover, science teachers do not seem to be encouraged to participate in professional development activities as a normal consequence of their professional role. In some occupations, applicants for positions are primed to ask their prospective employer questions such as, "Can you tell me about the opportunities that will be provided to expand my professional knowledge and skill if I come to work here?" Such an assertive approach would be unusual in teaching. Once again, we are confronted with a syndrome of passivity reflected in low expectations and modest claims in key areas of teachers' work conditions.

Feelings of guilt associated with; abandoning classes and forcing colleagues to cover their absence

A disincentive for involvement in professional development activities was the feeling of guilt that many teachers experienced as a result of being away from school and their classes. Science teachers have difficulty reconciling the benefits of professional development with the consequences of the absence from the classroom and from school generally. This sense of responsibility to the students is not uncommon among science teachers. Also, as much of the motivation for teaching is intrinsic and derived from interaction with the students, it is perhaps to be expected. However, this commitment limits their opportunities to update their professional knowledge and practice which is of paramount importance in fostering quality science teaching and learning. Ironically perhaps, this commitment thereby threatens to undermine the primary source of their job satisfaction.

A teacher in a Melbourne western suburbs school pointed out that

> I'm fairly committed to the classroom. That's partly why PD is a problem for me leaving the school. I know that if I leave the school for a day or whatever, my classes will be given work, but I like to get them into a routine where they know I will be there every single day, I will be there promptly. I find that's really important at this school as well.

Another disincentive to attend in-service courses is the extra work their absence creates for them. When teachers are working away from school, they have to prepare appropriate work plans for replacement/substitute teachers to follow. They also feel that the students are missing out if they are not there to teach their own class.

> I suppose the first few years, I wasn't really aware about how you went about doing them [in-services] in school time. I suppose too was the fact that you felt guilty about not being at school for the day because other people end up taking your classes.

It seems that even if science teachers could see the long term benefits for themselves, their students, and their school in developing themselves professionally, the daily pressures of classroom teaching were still of paramount importance. These are issues that have been aired before. Release for professional development is more difficult for teachers than people in most occupations. Maybe we will solve this perennial problem only if teachers agree to use out of school or holiday time on condition, for example, that (i) the quality of the courses is high, (ii) the 'savings' from not using substitute teachers is passed on to school professional development budgets, and (iii) successful completion of the course leads to eventual reward in salary and career terms. All of these are worth exploring when the implicit value of professional development is acknowledged.

Difficulty in articulating what counts as quality professional development

There has been a considerable advance over the past fifteen years or so in what we know about effective models of professional development. This research is well summarised in a number of publications (Eg. Commonwealth Schools Commission, 1988). This research reinforces the view that effective professional development is best if it is long-term and carefully planned with follow-up support. There are no short cuts to change in teaching methods or epistemologies. But few teachers indicated that they had an awareness of how to judge the quality of an in-service activity - the key components that would make it likely to help them add to their skills and understanding. As illustrated by these responses which were representative of science teachers' views, they were not critical consumers with a "Choice" magazine equivalent for in-service education available to them.

> Interviewer: And looking back, what for you, would be the most valuable sort of inservice?
> Science teacher: That's interesting, I don't really know. Content probably. What sort of books would I best look at...couple of good resource books possibly, to read for background...I'd be looking for resource material...Practical exercises, I can set them up fairly well.
>
> I think it's sparking off new ideas in people and sometimes you can do that at school, but very often you don't...For me it has got to come down to practical things...even basic things about how do you organise groups for particular activities.

Many of the science teachers we interviewed struggled to articulate what counted as quality professional development. A dilemma for many was that they felt as though they had not had enough experience of professional development to be able to make an informed statement. If they could put their present opportunities for professional development alongside what the research (Commonwealth Schools Commission, 1988) says about what is necessary to make qualitative improvements in teaching methods, they would have a right to feel rather angry with what they had experienced.

Teachers set a priority on activities that provided 'ideas' that were immediately usable in the classroom. If this was achieved, there was more acceptance of that professional development activity. In the short term, this is valuable to teachers as they search for new and innovative ways of improving their teaching and their students' learning. However, their sights were rarely focussed on longer-term goals for enhancing their professional knowledge and skill. Similarly though, it was not common for them to have experienced activities that focussed on this nature of their professional development. As a consequence, some teachers (as young as thirty years of age) even expressed the view that they were 'past it' in terms of having anything more to learn about teaching.

Minimal relationship between professional development activities and shifts in their pedagogy

Unfortunately, it was not common that science teachers noted much - if any - change in their teaching as a result of professional development activities. It would seem reasonable to expect some impact on their classroom teaching if: i) time was made available, ii) professional development activities catered for science teachers' needs, iii) they could 'tear' themselves away from school for half a day or a day to attend, iv) there was ongoing support, v) they were likely to be rewarded for involvement or enhanced qualifications, and vi) the participants valued their experiences.

As we have already outlined, these conditions are not common therefore responses like the following are in a sense inevitable.

> It was interesting [in-service], but I didn't find it to be particularly enlightening...it made no difference to the way in which I operated at all.

There were exceptions to this but they were when participants had clearly noted a need for professional development, sought out and attended an appropriate course, and instigated changes in their teaching to improve the quality of science teaching and learning in which they were involved. In-service programs that were cited as leading to shifts in teaching methodology involved a much greater time commitment than most of our teachers had experienced over the previous two years.

> ...it was using the concept of "collaborative friends" as described in the action research...They set up a number of teachers...looking at some of the techniques and methodologies, the concept mapping, the mastery learning, criterion-referenced mastery learning, the students working through the flow sheets, and giving them the chance to have more control...I found that quite fascinating...it was a peak and I think that kind of reflective time is a most important time for many teachers in their professional development...then it became a write-up and to assist us in the documentation, the Research and Planning people were involved, so they came down and spoke to students at this school about my teaching strategies and their learning strategies, and how that was significantly different from other classes they were in...One little thing that I tested was the use of concept maps...they had a terrific discussion on how to draw it and what the linking phrases were...

Significant changes in attitude and skill take considerable time. Programs that lead to changes in pedagogy are time consuming, expensive and require an ongoing commitment. But the opportunities for such involvement have been limited and in the current economic circumstances they are likely to remain so. As a result, most teachers appear to live in a kind of hand-to-mouth, subsistence economy with respect to professional development. They catch what they can on the run, as time and opportunities are limited, with few chances to build up knowledge capital through some form of study leave. Perhaps it is not surprising that teachers often stated that a form of professional development they found most useful was talking to other teachers, sharing ideas and hearing how others approached a topic. But, when asked if this was a common occurrence, the response was negative. It may be that professional development activities are not organised as if the most important source of professional knowledge is teachers' own experience. Teaching as an occupation has not developed methods that give teachers easy access to each others' methods, and experience. Documenting this professional knowledge - subject specific pedagogical knowledge as some have called it, needs to be improved. Maybe teachers should be paid to do this, and establish a tradition of 'case literature' over time illustrating what the Australian Science Teachers' Association considers to be 'best practice'. Mr. Warren Fineberg, a research fellow with the SEPD project, has been conducting a project (CLASP - the Classroom Science Project) to try out the possibility of doing just this. The response from participating teachers has been very positive illustrating their desire to share their pedagogical content knowledge. This may also reflect how science teachers' views of professional development are tied to the intrinsic rewards they receive from such activities that enhance their own classroom practice.

CONCLUSION

Our interviews with science teachers were an invaluable source of ideas and information about P.D. We have been able to present only a small proportion of that data in this paper, but we feel that it illustrates a profession that is increasingly left to cope on its own with many changes and demands placed upon it. We feel that professional development should be related to a science teacher's career development. The opportunity for science teachers to develop professionally and to maintain effective contact with their fields of expertise is limited. The need to strengthen these connections is readily apparent. There is little opportunity for

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teachers to develop the skills to enable them to do their job better; there also is little incentive.

In Britain, similar concerns about science teachers' professional development are also emerging. Nott, Watts and Oakes (1992) describe how a recent survey of science teachers illustrates how uniformed science teachers are about the opportunities for in-service education, and how little control they have over their own professional development. Nott et al. highlight the need for career development to be matched by appropriate professional development and that this be a right and a duty, not , "as it is at a present — snatched opportunities".

It is important that as a profession we are able to articulate what it is that a science teacher needs to know and be able to do. Science teachers as a group need to be more in control of their professional development. They need real opportunities to participate in meaningful professional development that does influence their classroom practice. This could lead science teachers to better control the important question, "What constitutes an Advanced Skills Science Teacher?"

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TEACHING ABOUT THEORIES OF LIGHT IN YEAR 12 PHYSICS: AN HISTORICAL APPROACH

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ABSTRACT

This paper examines an approach to the teaching of a year 12 Physics topic from within an historical setting. The Victorian Physics course requires teachers to cover each topic within some particular prescribed context, so that the everyday relevance of physics or its interrelationships with other fields of endeavour can be demonstrated. The Light and Matter topic specifies only one context: Landmark Developments. Rather than adopting a 'names, dates and events' approach which, for many understandable reasons, most teachers seem to follow, the author has attempted to cover the history in greater detail and more holistically.

THE VICTORIAN YEAR 12 PHYSICS COURSE

Course Structure

The new Victorian Certificate of Education program has resulted in significant changes to the Physics course at both years 11 and 12. As with any curriculum changes, there are the inevitable changes in the topics prescribed and in the way each topic is approached. A new direction was indicated in Physics with the introduction of Contexts specified for each topic. Instead of what may be regarded as the 'usual' treatment – that is, primarily a theoretical, conceptual emphasis with references to 'objects', 'masses' and 'individual charges' – each topic is to be taught within a framework which has relevance to everyday situations or which relates to a social or historical issue. Many teachers would have used such examples in the past without such an approach being formally prescribed for the course; the VCE simply gives the approach an official status and encourages all teachers to adopt it.

Historical Contexts

Several Areas of Study in years 11 and 12 include an historical setting as one of the Contexts around which teachers could choose to develop the topic. *Landmark Developments* is the only Context prescribed for the Light and Matter topic.

The historical, sociological and humanistic aspects of scientific progress throughout the centuries have, especially in recent decades, been proposed in various educational forums and journals as an effective way of covering 'normal' scientific content (e.g. Matthews & Winchester, 1989; Hills, 1992; Gauld, 1991). However, in addition to its contextual use, the approach is also of value from the point of view of demonstrating how scientific knowledge comes about, what causes changes (or stability) in that knowledge, and the tentative and subjective nature of science as a human endeavour. The new VCE course gives some emphasis to the approach.

A DIFFERENT APPROACH

During 1992, the author undertook to teach the *Landmark Developments* context for Light and Matter in the second semester of the year 12 course. The approach used provided the students with an opportunity to become aware of the 'nature of science' issues referred to above, while still covering the necessary general principles prescribed in the Study Design.

Classes were run along the lines of role-playing sessions, in which each student acted as a particular scientist for the lesson. An important aspect of the treatment was to get students to appreciate the significance of each idea and development as it would have been seen at the actual time it occurred. The work of scientists in the past is trivialized and belittled if it is simply categorized as 'wrong' when viewed with the benefit of hindsight from our current position. Similarly we are not entitled to be over-confident about the correctness of presently-held theories.

At the beginning of the topic, there was some preliminary discussion of the general state of, and approach to, scientific development up to the end of the fifteenth century, with particular emphasis on the external influences on scientific thinking, the concept of the ether, properties and theories of light as they were then known, and on the standing of Aristotelian physics at that time.

Detailed notes had been produced for a large number of scientists whose work was relevant to the topic, beginning with Descartes. Others included Snell, Huygens, Hooke, Newton, Euler, Young and Fresnel. This required a significant amount of research and then some decision-making as to just how much history could be included to provide sufficient richness and breadth, while ensuring that the Central Ideas, as specified in the course, were still covered.

Each student was given these notes for a particular scientist and, in some cases, an extract from an important publication by that scientist. The student was to study these notes and be prepared to discuss that particular scientist's ideas and contributions during the next couple of lessons, by acting out the role of the scientist in response to questions and discussion directed principally by the teacher.

Other students were to keep notes on these discussions for their Light and Matter File, as specified in the Work Requirements. This required them to attend regularly, as only one student had the written information on any one scientist and any absence by others would result in their missing important discussion. In addition to this student role-playing activity, some 'experiments' (for example, Young's experiment) were performed.

The notes which students made on all of these activities, and the information which they contributed in discussion, all comprised the Light and Matter File which they were required to maintain as their Work Requirement.

Details of Emphasis

The outline (see Box 1) indicates the general direction taken for the topic from the early 1600s up to about 1830, that is, until the time when the wave model as proposed largely by Fresnel had been had been developed sufficiently to the point of being published as a complete theory in the literature.

Throughout the topic, in addition to following 'Landmark Developments' through the ideas of scientists since 1600, the broader interests of the scientist, his standing in the scientific and wider community and the processes of scientific communication at the time were also examined when the opportunity arose. These aspects were included not as isolated anecdotes but to help create an overall picture of the people involved in science; to humanize them and to add further dimensions to the personality of each one. The nature of scientific theory and the way it changes were other aspects which were emphasised throughout the topic.

BOX 1

Descartes
- believed light to be an instantaneous phenomenon
- lived in Leyden during the later 1620's and early 1630's
- published La Dioptrique in 1637 and this included a description of an analogy for refraction based on a tennis ball being struck at an angle towards a thin penetrable sheet of material
- derived, in La Dioptrique, a law of refraction equivalent to what is now known as Snell's law
- thought of light as a wave rather than a particle, despite the analogy with a ball
- was one of the first scientists to try to develop a mechanistic view of natural phenomena.

Snell
- born and lived in Leyden
- derived a law of refraction (in about 1621) but did not publish it.

Huygens
- developed a wave model for light which included the idea that a wavefront could be considered as being made up of many closely-spaced point sources each producing circular waves which combined with each other to make a new wavefront having the same shape as the original
- was accepted as an authority in optics by the fledgling Royal Society and was asked to review Newton's first paper prior to publication in Philosophical Transactions
- was acquainted with Hooke, Oldenburg and others in England on an on-going basis, as well as with Newton, although he first met the latter only in 1689.

Hooke
- was an early member of the Royal Society
- was involved in investigations related to optics and gained a reputation as an authority in that area
- published Micrographia in which he described his understanding of light in terms of an instantaneous pulse through the ether
- was asked by the Society to review Newton's first paper and subsequently became involved in a long-running dispute with Newton.

Newton
- first began investigations into light in 1664 at which time he was interested in refraction, dispersion and the nature of colour
- developed a particle theory of light in detail which was eventually explained in Opticks in 1702 and in subsequent revisions
- described reflection, refraction, beam-crossing, dispersion, total internal reflection and many other phenomena by attributing to the particles such characteristics as differing size and mass as well as being in alternate states (or 'fits') of transmission and reflection; these collectively enabled a reasonable set of explanations to be drawn together for many of the then known properties of light.

Four different models of light (Cantor, 1983) could be described as having some following during the seventeenth and eighteenth centuries. Cantor labels these as the Projectile theory, the Wave theory, the Vibration theory and the Fluid theory.

Eighteenth century developments
- confirmation and fairly general acceptance of a value for the speed of light based on planetary observations by Bradley (based on an earlier proposal by Romer who was unable to calculate a specific speed owing to the lack of a value for interplanetary distances in his time)
- widespread influence of Newton's ideas and their passing on to the general population through lectures which were directed towards and well attended by the public
- debate surrounding particle and vibration models, especially the use of the persistence of vision phenomenon to reduce the required number of light particles in a beam and so overcoming the problems of light scattering in crossed beams and of 'wastage' of matter from light sources
- Leonhard Euler (mid 1700's) and his vibration theory.

Young
- worked towards a law to explain the interference phenomenon rather than developing a theory of light.

Fresnel
- developed a mathematical analysis of wave motion (as distinct from a description based on mechanical vibrations within an ether) as a basis for a theory of light.

Arago
- provided much of the encouragement to Fresnel to continue with his work
- during trips to England from France, established and maintained contact with Young and acquainted Fresnel with the former's work.

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SOME EXTERNAL RESTRICTIONS

It is difficult to maintain students' interest and enthusiasm in a Year 12 subject if they realize that the work does not directly relate to their formal assessment. There was some student concern, at times, during the topic because they felt that they were spending time on non-assessable material. The course requirements also specify that students must complete certain set work throughout the year and, for this topic, they were to maintain a File of the developments related to theories of light. This appeared to be sufficient to ensure adequate student involvement. Nevertheless, because the end-of-year examination did not require knowledge of historical aspects, some limits needed to be placed on the extent to which this approach could be developed.

A second constraint was the time which could be devoted to this topic, with respect to the course as a whole. Taking other topics into account, there was not much more than three weeks available for Light & Matter. This placed a severe restriction on any attempt to meet the course content requirement while, at the same time, enabling the students to gain any real appreciation of the development of scientific ideas.

COMMENTS ON IMPLEMENTATION

These restrictions did have some effect on the successful conduct of the topic, in that the author was unable to develop it as fully as would be required to address both the course aims and those of the historical approach. Nevertheless some useful information was obtained from the trial.

Initial Student Impressions

When the topic was first explained to the class, most students seemed interested in the different approach, and some actually commented that it would make a change from the normal development of a topic. Some were concerned to know whether they had to remember dates and other historical details for the examination and so were a little sceptical about the proposed emphasis, but this did not show itself to be a problem as the topic unfolded.

Directing students' thought processes

It took some time for students to understand how to orient their thought processes for such an approach: they often wanted to know whether each point of view or proposed theory was the 'right' one or not (in terms of today's scientific thinking). It was only after continually being told that their question would not be answered and was, in a way, irrelevant that they began to show some understanding of how to deal with the approach. They became more interested in gaining a clearer understanding of a scientist's outlook or to question a scientist's arguments (ideally, only using knowledge which would have been available during the era under discussion). A study of the history of a set of scientific developments does not do justice to the contributions made by various scientists if their ideas are branded from the start as 'wrong'. It is important to see the significance of each idea, how it evolved or was modified, how many schools of thought there were at any one time, and how and why an idea was superseded. This is done most effectively if the ideas are studied in their contemporary context rather than simply compared with our present day notions.

It was important to emphasize to the students that they should all try to place themselves actually in the era being discussed (rather than being students in a physics class), so that any comments or questions they offered should arise as if they were another contemporary scientist; that is, the whole class was encouraged to role-play in the historic setting as much as possible.

Student Attendance

A significant management difficulty arose in the early stages of the topic: progress depended heavily on the attendance of the student chosen to be a particular scientist and the satisfactory preparation of the required work. It was confusing to consider the ideas of a later scientist and wait until next lesson for the absent student to present the earlier material. If the absent student's work was simply presented by the teacher to the class some of the impact of the approach would be lost. It was decided that this difficulty could be overcome by giving the notes on each scientist to three students, all being expected to make some contribution in the next class: if a student did not attend, the topic development was unaffected and the non-attender had to make arrangements to discuss the scientist with the teacher at some later convenient stage, to verify that their study had been done. This change in the 'mechanics' of the topic meant that the original list of scientists (some two dozen) could not feasibly be given to students, as each student would have three times as many scientists to study. Consequently, just the 'main' scientists (those listed earlier in this article) were given to students and the author gave a short discourse on the 'lesser' scientists, as their contributions became relevant to the era being covered.

Material provided to students

On reflection, a number of the scientist summaries which were put together probably drew too broad a picture without providing sufficient detail of their work in optics specifically. This was a consequence of the somewhat artificial situation regarding the compromise between, on the one hand, the historical approach as the author would like to see it (that is, painting a fuller picture of a scientist's involvement in science) and, on the other, the time and assessment requirements of the VCE course.

Pedagogy

The detailed management of each class – conducting and directing the discussion/debate/role-playing etc., while at the same time dealing with questions as they arose – provided a challenge. This would be less of a problem with further practice, with greater general understanding and knowledge of the topic, and with better student understanding of what is expected of them. In this latter regard, it seems that the student-scientists need to prepare their notes or talk on the basis of conveniently-sized periods of time during the life of the scientist being investigated. They would explain (uninterrupted) what they (the scientist) had been doing during that period and then there would be opportunities for other class members to become involved in questions or discussion, or for some other contemporary scientist to deliver their recent deliberations. As it happened in this first trial, the discussions tended to be more of an exchange of brief comments between the teacher and the student rather than more general discussion within the class as a whole. It would also be beneficial if there was some discussion (a 'rehearsal') with each student-scientist a day or two before their class contribution, to ensure that they understood the material. This would also enable any experimental demonstration or practical activity to be planned so that the student could take a leading role in introducing it to the class.

An attempt will be made in future coverage of this topic to find and include a greater number of actual experiments performed by scientists at the time and which could be feasibly carried out in class.

CONCLUSION

The role-playing approach enabled students to realize that scientific ideas continually evolve and that it takes some time before any new proposals become more widely accepted. The students were eventually prepared to discuss these ideas in the context of the era in which they were developed. They understood that a scientific theory does not reach a stage of finally being proved: one never knows what new observations will be made or what new ways of looking at nature will be proposed. The activities given to the students encouraged them to think differently, but there are other ways in which this could be done successfully - greater student involvement in direct research would be one of these. More than just the pedagogical technique is required, however, to achieve even this much. The main requirement for teaching physics using such an historical approach is for the teacher to appreciate the emphasis needed in the classroom so that the nature of science and the way knowledge grows is more clearly understood by the students.

The author found the time involved in researching the topic and planning the teaching method was extensive. If the approach is to be adopted more widely in schools, in-service education is required to enable teachers to study the development of science as a human enterprise and to discuss the differences in classroom approach which relate to an historical approach to teaching physics. Curriculum support is also necessary to make appropriate material available. This outline gives an indication of the content development and classroom management which could be part of such an approach.

There is much to be gained from teaching about the history of science, not only from the point of view of understanding the central concepts of physics, but also in understanding how we have come to our current position, the influences on the development of scientific ideas, the on-going nature of this development and the likelihood of changes in direction in the future.

Some appreciation of the human and developmental aspects of science can add a third dimension and extra colour to the 'breadth' of topics and 'depth' of theoretical understanding which comprise many physics courses currently presented in secondary schools.

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IMPROVING QUANTITATIVE VOLUMETRIC ANALYSIS SKILLS IN FIRST YEAR UNIVERSITY CHEMISTRY COURSES

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ABSTRACT

This paper describes a project in the School of Chemistry at The University of Melbourne. During 1992 thirty hours of videotapes were taken of students doing quantitative volumetric work in first year laboratories. These were viewed to find out what problems students encountered and what interactions they had with other students and with demonstrators. The data were logged on a Hypercard stack and novel visual images were produced to map student activity, both qualitatively and quantitatively. These data contributed to the design of a multimedia learning package which students worked through at the beginning of 1993. Video data of their laboratory performance after this intervention provides evidence of improved performance.

BACKGROUND TO EDUCATIONAL NEED

There is an urgent need to develop new and more effective means of teaching laboratory skills to first year chemistry students. Several problems have increased over the past decade:

- decreasing average level of preparation of first year students as judged by their chemical knowledge and manipulative skills on entry;
- increasing range of student ability and aspirations;
- increasing awareness of science education research that calls into question many of the traditional assumptions made about the role of practical work in teaching chemistry (e.g. Woolnough & Allsop, 1985);
- increasing economic pressure forcing university departments to examine the effectiveness of their teaching programs

Hegarty-Hazel (1990a) describes several content analysis studies of secondary and tertiary science courses. These studies reveal that technical skills are required in almost every student exercise but that exercises to teach specific skills occur fairly seldom. She concludes that "the potential therefore exists for students to encounter constant demands to use new skills and never become competent in any" (p. 83). Increasing unease about the level of student competence and a plan to totally revise the first year chemistry offerings at The University of Melbourne led to this project. During 1992 all first year science students studied the same chemistry course. In 1993, a three-level syllabus presented in three separate streams was introduced.

There is a wide variety of contexts in which university practical work is carried out _ from highly directed exercises to open, exploratory projects. Findings from studies need to be interpreted in the framework of the nature and purpose of the practical work. Hegarty (1978) does this in terms of five levels of scientific enquiry. This project is involved with highly directed exercises aimed at teaching students' basic skills in quantitative volumetric analysis.

Desired student outcomes

The members of the project team defined the following desirable student outcomes for the components of first year chemistry studies which involve quantitative volumetric analysis:

- understanding of community importance of chemical analysis;
- knowledge of techniques and procedures of quantitative volumetric analysis;
- knowledge of theoretical procedures for interpreting laboratory results;
- development of manipulative skills appropriate to successful quantitative volumetric analysis, including quantitative transfer of solids and liquids, pipetting to 0.02 mL and titrating to 0.05 mL.

The project included:

- collection of background data establishing current laboratory practice in first year laboratories;
- development of a computer-based learning (CBL) module on quantitative volumetric analysis;
- the examination of the computer log records that students produce as they work through the CBL module at various stages of development, using students from a range of educational backgrounds;
- monitoring of students' enjoyment and appreciation of the developed curriculum materials;
- formal laboratory skills assessment of those who have used these materials;
- investigating ways in which these materials might be used within the overall laboratory program.

The time line for the project is given in Table 1.

TABLE 1
TIME LINE OF CHEMISTRY LAB PROJECT

Time	Activity
Beginning 1992	All first year chem. students do the same subject
Beginning 1992	Written test 1 to a sample of first year chem. students
Semester 1 1992	30 hours video of chem. labs Listing of errors & computer-based analysis of data
End sem. 1 1992	Written test 2 to all first year chem. students
July & Oct. 1992	2 sets of formative evaluation of CBL module
Beginning 1993	Change in 1st year chem. course structure to 3 streamed subjects
March 1993	Chem 161 students & demonstrators do CBL module
March 1993	Video of lab classes of all 3 chem. subjects Student interviews using computer log records

BASE-LINE DATA ON FIRST YEAR STUDENTS' SKILLS

Written test 1 at the beginning of semester 1 1992

This was a simple test where approximately 10% of the first year students were asked to identify pieces of equipment and state their function, e.g. burette, pipette, standard flask, conical flask, beaker, measuring cylinder etc. They were asked how many titrations they had done and were asked to describe the process of titration and give an example. Most students had some experience of performing titrations. Students could easily recognise basic equipment but had little idea of the accuracy of the equipment. Thirty per cent of the students had a clear idea of the principles and procedures underlying titration; 20% of the students had no clear idea at all of titration.

Video analysis of first year chemistry laboratories

Studies of science laboratories at tertiary level have largely been of the interaction analysis type as is this investigation. Interaction analysis involves the data about student behaviour being collected by observation (including the use of videotape) and then analysed according to a specific set of categories. Hegarty-Hazel (1990b) reviews several such studies from the 1970s and 1980s.

The videos provided information on the way students divide their time in the laboratory between experimental work, bookwork and discussion, on the difficulty, outcome and repeat rate of operations, and the interactions of students with demonstrators and peers. An unattended video camera was arranged in a student laboratory so that it pointed down the length of one bench. It was unattended and remained stationary throughout a practical session. Students were aware of the video process and seemed totally unconcerned by it. The tapes were analysed in two ways, one attempting to determine errors in students' technique, and the other intent on capturing timing and interaction information.

In order to look for errors in student technique, the tape was played at double speed with the observer watching only one student. This was fine for errors that occurred frequently and were easily identified; however, when more unusual errors occurred it was often necessary to slow the rate of playback to real time and occasionally replay sections of the tape. This method was found to be successful. Of course, more than one student was in the picture at a time and so it was possible to replay the tape many times to observe the activities of several students. The number of students analysed per tape was dependent on the layout of the laboratory equipment and the angle of the camera. It was possible to observe more students when they were working in pairs and groups of three than if they were working individually because there was less equipment blocking the camera's view. Data were collected from the activities of 14 students by this method.

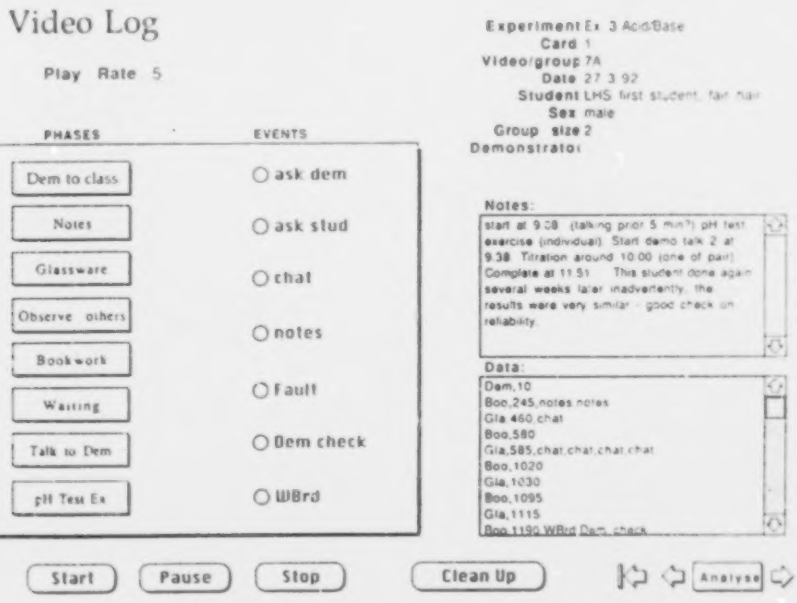
The errors noted fell into three main categories:

- preparation of equipment for titration, especially rinsing procedures;
- level of care taken and concern for accuracy;
- lack of regard for the consequences of decisions. Students perform procedures without thinking of the likely consequences of their actions.

All of these issues are related to a lack of appreciation of the relationship between the various steps in a titration. It is not just a matter of following a recipe; there are clear theoretical reasons for each of the steps involved. Gardner and Gauld (1990) suggest that the lack of integration between theory and laboratory may be a factor in students developing poor attitudes to science. We believe students' inability to see a procedure in a holistic way is part of this theory/ practice divide and this was a significant principle on which the CBL module was based.

As with the error analysis, the interaction analysis focussed on one student at a time. The procedure involved playing each tape on fast forward at between five to seven times real time; a Hypercard stack was used to record the amount of time the student spent using glassware, doing bookwork, talking to other students, interacting with the demonstrator, etc. Two observers were necessary for this, one to operate the mouse and locate the appropriate buttons on the screen and one to continually watch the video and call out the phases and events as they occurred. Through this process, data was gathered about the main activity at any time (called a phase) and also particular events occurring during each phase.

Fig. 1 shows a screen from the Hypercard stack used in the analysis; this shows the phases and events together with the notes made by the observers and the data log. It is possible to visually map the experience any individual student has from the Hypercard data. Thirty-seven students were observed and mapped in this way and one example of these maps is shown in Fig. 2. The record of phases and events is shown at the bottom of the map. Frequency of interactions are shown by the width of the shaded areas. Times spent on various activities are indicated. The box 'check' indicates times when the demonstrator checked on the student; the box 'demonstrator' indicates times when the student actively sought help from the demonstrator; for the student in Fig. 2, the demonstrator initiated contacted both during the 'hands on' and 'bookwork' phases; the student did not seek help from the demonstrator at all. 'Class demo' is the phase where the demonstrator explains the practical and usually build up a white board summary, mostly at the beginning of the laboratory session; in the practical session shown in Fig. 2 there was also some additional whole class teaching during the session. 'Student' indicates student-student interactions which, in Fig. 2, occur more during 'bookwork' than during the 'hands on' phase. It was quite difficult to distinguish the events 'ask stud' and 'chat' (events listed in Fig. 1); it appeared that most talk was work-related and this fits with the experience we have all had: students are certainly on-task during laboratory sessions. 'Notes' indicates clear reference to the laboratory manual; the student map shown indicates little of this.



Play Rate 5

Experiment Ex 3 Acid/Base
Card 1
Video/group 7A
Date 27 3 92
Student LHS first student, fair hair
Sex male
Group size 2
Demonstrator

Notes:
start at 9.08 (talking prior 5 min?) pH test exercise (individual). Start demo talk 2 at 9.38. Titration around 10.00 (one of pair) Complete at 11.51. This student done again several weeks later inadvertently, the results were very similar - good check on reliability.

Data:
Dem,10
Boo,245,notes,notes
Gla,460,chat
Boo,580
Gla,585,chat,chat,chat,chat
Boo,1020
Gla,1030
Boo,1095
Gla,1115
Boo,1190,WBrd,Dem, check

Fig. 1 Hypercard screen for recording interaction analysis

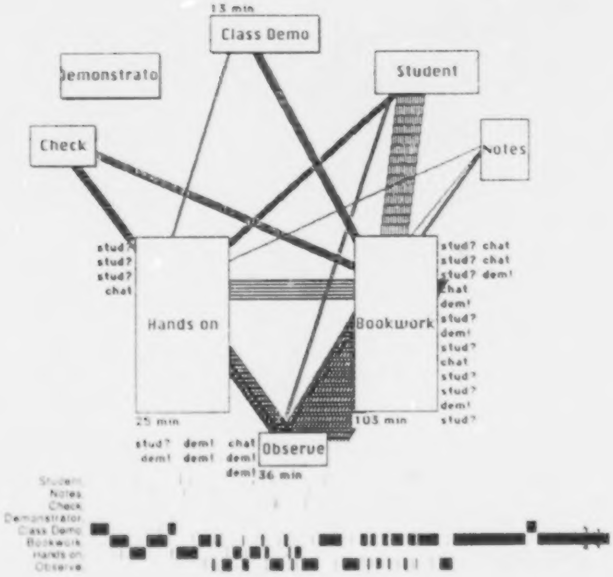

13 min
Class Demo
Demonstrato
Student
Check
Notes
stud?
stud?
stud?
chat
Hands on
25 min
stud? chat
stud? chat
stud? dem!
chat
dem!
stud?
dem!
stud?
chat
stud?
stud?
dem!
stud?
Bookwork
103 min
stud? dem! chat
dem! dem! dem!
dem!
Observe
36 min
Student
Notes
Check
Demonstrator
Class Demo
Bookwork
Hands on
Observe

Fig. 2 Example of a map of student experience in a laboratory session.

A map for one male student is shown who was part of a group of three (though students should have been working in pairs). The other students (both females) did most of the practical work; even so, they spent more time in bookwork than on practical activities. The male was excluded and only permitted to do 25 minutes of washing up during the three hour laboratory session. He spent a great deal of time (36 minutes) just passively observing. None of the three students interacted with the demonstrator much.

The video analysis reveals two serious problems:

- the relative time spent in practical work and writing up. Table 2 records these times. There is clearly a large amount of time spent in bookwork. Only in the third practical listed is the vast majority of time spent in practical work and this is a very full session indeed. Even when a result sheet is provided, the time spent in bookwork seems high. Some of this time is spent in consulting notes but during most of it the students are writing.
- lack of interaction with demonstrator, especially during hands-on time. This is clear in Fig. 2 and this is so for all the students.

This style of video analysis was successful in many ways as it was possible for more than one person to observe the class without intruding on the students too dramatically. Similarly, accurate data on several students can be obtained from one session and this would not have been possible if a casual observer had been situated in the class instead. The production of visual maps is novel and has been very beneficial in explaining and discussing issues related to laboratory work. The main drawback from the method is that the viewing of techniques was blocked by pieces of equipment or other students standing in front of the camera. For example, the laboratory is designed so that there is a sink at each end and often students stand around washing glassware with their backs occupying the majority of the picture from the camera. Also this style of analysis does not have speech recorded.

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TABLE 2
HANDS-ON AND BOOKWORK TIME

Expt		No. students viewed	Hands-on (minutes)	Bookwork (minutes)
1.	Calibration of pipette (1 hour) beg. March 1992	11	13	32
2.	acid-base titration/pH (3 hours) end March 1992	12	53	90
3.	Zn^{2+}/EDTA titration; prep Cu^{2+} salt; stand. $S_2O_3^{2-}$ (3 hours) beg. April 1992	7	113 (quite a lot of waiting for balances)	20*
4.	$Cu^{2+}/I^{-}/S_2O_3^{2}$ titration (3 hours) end May 1992	7	77	49*

* result sheet provided

Written test 2 at the end of semester 1, 1992

This test was given to all first year students. Students were able to describe how to clean and rinse individual pieces of equipment; over 80% answered questions on this correctly. However, they were less able to design procedures from a combination of steps; between 50 and 80% of the students answered these questions correctly. Very few students could answer questions related to the effect on accuracy when drips, drops and bubbles are not correctly dealt with during titrations. Ninety per cent could calculate concentrations correctly but only 63% could calculate errors and only 30% could state the correct number of significant figures in a calculation.

Clearly, these data obtained in 1992 show room for improvement in the teaching of quantitative volumetric analysis.

DEVELOPMENT OF COMPUTER-BASED LEARNING MODULE

Other methods of support and tuition used previously include summaries, flowcharts, checklists, diagrams, photographs, slides, movies or videotapes (Hegarty-Hazel, 1990a, p. 81). Some studies on university chemistry practical courses report favourable results from the use of videotapes (e.g. Kempa & Palmer, 1974; Neerinck & Palmer, 1977), diagrammatic overviews (e.g. Beasley, 1979), and audiotapes (e.g. Runquist, 1979). The team for this project designed a package including a computer-based learning module supported by a checklist partially produced by students and a video to be used at the beginning of the laboratory session.

The CBL module uses a Hypercard-based tutorial generator (called TutorialTools), developed at The University of Melbourne. It allows for:

- various formats for tasks and questions, including fill-in comprehension items, multiple choice items, arrangements of flow charts, and simulations. The use of Quicktime video clips on screen, and graphic animations of reactions and processes increase the flexibility in design enormously.
- various levels of interaction and feedback. Students can ask for hints, or for fuller explanations.
- multiple sessions. With class sizes of well over 1 000 students, the efficient delivery of CBL modules is essential.

This is a new curriculum strategy. Prosser and Tamir (1990) have examined the use of computers in student laboratories. While computer-based simulations have been used in student laboratories for some time (e.g. Butler & Griffin, 1979), they tend to focus on the use of specific instrumentation (such as spectrophotometers) and on the calculations involved in analysing data. This project has produced a CBL module which focuses on the design of a sequence of practical skills which together form an important technique. It is this integration of parts to form a whole that is novel.

Formative evaluation
In July and October 1992 two sets of formative evaluation were carried out with 12 students. Because the students spent quite a lot of time on this exercise, a small payment was given to them.

A strategy called the 'think aloud video' (Gomoll, 1990) was employed. This involves some training of students to articulate the reasons for the choices they are making and their reactions at the outcomes as they go through the program. Students were told that we were interested in impressions of the program from a user's point of view so that we could improve its interface design and overall teaching effectiveness. They knew it was prototype material and they would encounter incomplete sections, problems or points of confusion as they worked through it. They were asked to verbalise their thoughts and reactions as much as possible. We were interested in information about situations where they were confused, trying to find something, frustrated, missing information, misunderstanding instructions or content, surprised by the actions of the program, pleased, interested, etc.

The whole process was videoed. This strategy can provide rich data about students' thinking as it occurs. Observer bias is more or less eliminated. In reality, we found that we somewhat overloaded students because we were asking them to respond to issues in screen design as well as their own processing of the content material. As a consequence, some prompting from staff occurred during the process. Also, at the end a short interview was carried out with all the students to find out about their overall interest in chemistry, their familiarity with computers, amount they felt they had learnt from the module, their impressions of the various formats used in the module, etc.

The students' choices were logged by the computer. Their responses to questions, use of menu options such as help and pop-up topic list buttons, and the time they spent on various cards were all examined.

These formative evaluation exercises provided feedback to the project team which resulted in significant changes to the design of the module. Some examples are:

- Simplified navigation. Traditionally a bar across the screen (often at the bottom) was used with several icon buttons which students could select in order to access pats of the program. Students now use the mouse to click on a single button with a pop-up menu.

- Improved visualisations. In many cases, students did not focus on aspects of diagrams that we had hoped they would. For example, in a graphic animation of all the steps in a titration, none of the students studied what we had thought were key labels; they focussed only on the moving equipment. The labels were changed and supported by side text.
- The style of on-screen help. The use of small side notes is now used as well as the conventional help menu off-screen
- Removed a complex simulation. We had originally planned to include a full simulation of a titration with students being able to follow visually all the steps involved and make decisions about reading the meniscus, when the endpoint is reached, etc. This was technically difficult and a great deal of effort had gone into our prototype; however, it really did not teach students better than a demonstration in the laboratory setting could. Arons (1984) cautions about the production of unnecessary materials. It is hard to remove an elegant piece of programming from a module; only with a clear evaluation focus which puts student learning at the focus can useful materials be produced. Incidentally, the titration simulation may well become part of a lecture demonstration for pre-lab sessions and there its use may be appropriate.

So, students were involved both in the development of the program and in the evaluation of the final product. The process of the development of an interactive computer program is one which can be a valuable learning experience for students and this we found to be the case.

EVALUATION IN 1993

In 1993, three chemistry courses were formed: Chemistry 121 (students with good year 12 chemistry scores), Chemistry 141, Chemistry 161 (a terminal subject; about one-third of the students have not done Year 12 chemistry). In addition the laboratory structure was changed and all exercises have been revised or rewritten. Laboratory classes now alternate with three-hour workshops.

In March 1993 all the Chemistry 161 students and their demonstrators did the CBL module during the workshop slot the week before they performed their first titration. Students also completed a checklist during the computer session for later use in the laboratory. They also watched a video which reviewed essential steps at beginning of the laboratory class. Three strategies were used in the evaluation.

On-screen evaluation This involved approximately 70 students. Students filled in a checklist asking for their reactions to the content and form of the module. Without exception the response was overwhelmingly positive and this has been true of all the CBL modules given to first year chemistry students in 1993. Students' positive reaction is important but it is important to also gain evidence about whether they learnt from the module. This was done in two ways.

Interviews using computer log records This was only done with four students because of the large amount of time involved. In this strategy students with various backgrounds were selected: no previous study of chemistry, repeat student, and two students who were more typical of the class as a whole. There were three females and one male. Their logs were examined by the interviewer and, soon after they had studied the module, the students worked through the module again with the interviewer. In essence they were asked to 'relive' their experience. The reasons for errors and delays could be probed and the amount of learning could be gauged by presenting students with similar problems. A great deal of information about particular items was obtained this way to enable further fine tuning of the module. All four students had indeed learnt an appreciable amount from the module. What was very interesting was that different students learnt different things from certain screens. This was particularly true of the items dealing with the concept of the mole and the overall process of titration. This aspect of the 'robustness' of a CBL module is one which is important as an increasingly diverse groups of students study first year chemistry courses and is an aspect of CBL evaluation which we are pursuing further.

Laboratory videos of all three chemistry courses All three chemistry courses have an introductory titration exercise. Only the Chemistry 161 students and their demonstrators studied the CBL module. Videos were taken of all three courses doing this introductory titration exercise.

Twelve technique points were examined on each video. These were:

* the preparation of flask, burette, beaker and pipette (4)
* the use of a burette with respect to using a funnel, checking for air bubbles and reading the level correctly (3)
* the use of a pipette with respect to the technique for filling, checking the meniscus level, draining it vertically and touching the tip against the flask (4)
* addition of half drops at the end of the titration (1).

Each technique was judged and assigned a score on a correct/ incorrect basis. These scores were then added for each student. The average score was then calculated for each chemistry stream. The Chemistry 161 (N=25), Chemistry 141 (N=14) and Chemistry 121 (N=15) students averaged 71%, 60% and 60% respectively. The whole procedure involves subjective judgments and in no way is intended to be a rigorous statistical procedure. However, it does emphasise the holistic nature of scientific techniques; laboratory skills are composite. Skills competence is a context-dependent concept (White, 1979); in the context of a first year chemistry laboratory it is difficult for students to appreciate fully the need for accuracy and hence the emphasis in this project has been on the total process rather than on just attaining proficiency in the individual steps.

It is very satisfying that students with either no formal prior study of chemistry or limited success therewith perform as least as well as students whose previous achievements in chemistry are higher. Of course, the satisfactory performance of these students cannot be ascribed to the CBL module alone. Part of the effect is likely to result from the demonstrators also studying the CBL module, all of whom appreciated the experience and reported favourably on both enjoyment and learning. The lack of adequate training of demonstrators is a weak link in many laboratory renewal schemes. Also, the CBL module was used together with the checklist and the video. It is the total package which needs to be considered.

CONCLUSION

This project has enabled insights to be developed about the nature of the experience students have in first year chemistry laboratories. The visual maps of their experiences are useful in staff development and curriculum renewal work. We believe that the Hypercard-based mapping technique may well be of value in other education settings. The package of the CBL module plus checklist and video, together with some training for demonstrators, appears to be effective in assisting students learn basic quantitiative volumetric analysis skills. Further work with other CBL modules is ongoing.

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A CASE STUDY OF SCIENTIFIC REASONING

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ABSTRACT

Concern is increasingly being expressed about the teaching of higher order thinking skills in schools and the levels of understanding of scientific concepts by students. Metaphors for the improvement of science education have included science as exploration and science as process skills for experimentation. As a result of a series of studies on how children relate evidence to their theories or beliefs, Kuhn (1993a) has suggested that changing the metaphor to science as argument may be a fruitful way to increase the development of higher order thinking skills and understanding in science instruction. This report is of a case study into the coordination of evidence and theories by a grade 7 primary school student. This student was not able to coordinate these elements in a way that would enable her to rationally consider evidence in relation to her theories. It appeared that the thinking skills associated with science as argument were similar for her in different domains of knowledge and context.

INTRODUCTION

Many recent reports have acclaimed the need for more attention to the development of higher order thinking skills (Mayer, 1992). If the development of such skills is to be seen as a goal of science education it is imperative that we increase our understanding of what it means to think scientifically and of how students think when confronted with situations that could involve the higher order thinking skills associated with this mode of thought (Kuhn, 1993a). Further, research in Australian classrooms has often shown that many teachers focus on activities that promote rote learning in students rather than the development of understanding and thinking skills (Tobin & Gallagher, 1987).

Over the years, research on scientific thinking has taken a number of different approaches. These approaches have included the study of scientific thinking as combinatorial logic (Inhelder & Piaget, 1958) and the logic of deductive argument (O'Brien, 1987), inductive reasoning (Holland, Holyoak, Nisbett & Thagard, 1986), problem solving involving a search through different problem spaces (Klahr & Dunbar, 1988) and science as everyday thinking (Galotti, 1989; Reif & Larkin, 1991). Much of this research conceptualised scientific thinking as being either domain general (e.g. Inhelder & Piaget, 1958) or domain specific (e.g., Carey, 1986).

It is well established that many students have difficulties in learning science and that many hold alternative views that have proved remarkably resistant to change. From a conceptual change perspective, Glaser (1984) has proposed that the construction and revision of theories is at the heart of cognitive development. While considerable research has been reported about what children believe about particular science concepts, it is also important to understand how the process of theory change occurs (Chinn & Brewer, 1993; Kuhn, Schauble & Garcia-Mila, 1992) and how to build a learning environment to facilitate this restructuring (Duschl & Gitomer, 1991).

For some researchers, it is the differences in the goals of science and the kinds of cognitive processes required for the scientific domain when compared to the everyday domain, that are a source of difficulty for students learning science (Reif & Larkin, 1991). Much of the current research on inductive and deductive reasoning does not make links to everyday reasoning (Galotti, 1989). On the other hand, it is the commonality between scientific reasoning and everyday thinking that could be explored as a way to improve both kinds of reasoning. By considering scientific reasoning as argument, both informal and scientific reasoning may be seen as involving the justification of beliefs by considering the evidence relating to those beliefs and coordinating those beliefs and the evidence that supports them. It is further argued that thinking as argument is implicated in all the beliefs that children, adolescents and scientists hold, the judgements they make and the conclusions they draw when presented with particular evidence (Kuhn, 1993a,b).

In a series of studies, Kuhn and coworkers (Kuhn, Amsel & O'Loughlin, 1988; Kuhn, 1989; Kuhn et al., 1992; Schauble, 1990; Schauble, Klopfer & Raghaven, 1991) have investigated how students undergo conceptual change and how they coordinate their beliefs (theories) and evidence when investigating scientific phenomena. The results of these studies suggest that although the children's scientific reasoning utilised their prior theories or beliefs, this reasoning was not domain dependent in that there was still a generality and transferability across domains of the scientific reasoning strategies employed.

Over the years there have been a number of different approaches and metaphors adopted to guide teaching and research in science education. From their observations, Kuhn and her coworkers (in the studies reported earlier) have argued that these approaches have not met the essential challenge facing students in investigating phenomena (Kuhn, 1993a). Science as exploration has been one such guiding metaphor, but this metaphor presents a problem: although it is an appropriate description of what young children do in scientific activities, it is less observable in older students. Another approach has been to develop the traditional experimental strategies of hypothesis testing and inference. This work acknowledges that these are important tools to be developed, but suggests that the major difficulty lies elsewhere. Conceptualising scientific thinking as argument and linking it to the processes of thinking in everyday contexts, rather than trying to link it to what the children know from the everyday context, may well prove to be a new and fruitful metaphor to guide science instruction and research (Kuhn, 1993a).

The aim of this study was to investigate how student beliefs interact with their reasoning strategies in different contexts.

METHOD

One of the more able grade 7 female students in a Brisbane primary school (Kate) was selected for this case study. The student was interviewed to ascertain her beliefs about the effects of variables in four different investigations, her interpretation of presented evidence and her generation of evidence to both support and not support her beliefs for each investigation. She was further asked to list all possible combinations of three selected variables relating to each investigation. The investigations selected related to the characteristics of toothpaste that are the cause of good teeth in children, the manufacture of frying pan handles, dry cleaning solutions and the conductivity of metal rods in a laboratory conductivity apparatus. The first two of these investigations related to contexts involving everyday applications while the second two related to contexts of laboratory type applications. The first and third involved few scientific concepts. For example, the variables in the toothpaste investigation were like those shown in Table 1 and the dry cleaning substances were only identified as substances A, B and C in liquids 1 and 2. The second and fourth investigations were designed to involve related scientific concepts. For example, the conductivity apparatus and frying pan variables included cross section, length, type of metal, brightness of surface. Thus a range of investigations across context and type of concepts was investigated. The sequence of interviews following was presented over a three week period. The same procedure was followed for each of the four contexts, the evidence evaluation procedure was first conducted for each context, followed by the evidence generation and combinatorics procedures for each of the four contexts. The interviews were based on related studies by Kuhn (1989) and are outlined with reference to the investigation of the characteristics of toothpaste that cause good teeth in children.

Evidence evaluation and predictions

The student's beliefs about which variables of toothpaste were causal in determining the quality of teeth in children and which variables were non-causal were determined after discussion of eight possible variables. Each variable was also rated on a scale as to how sure the students were of the stated effect. From the list of variables considered, the two causal variables (e.g. presence or absence of fluoride, high cost or low cost) and two non -causal variables (e.g. advertised or not advertised, in a pump or in an ordinary tube) which represented the most strongly held beliefs were selected as the basis for the next part of the study.

A story was told establishing that scientists were conducting a series of studies to ascertain the variables that affected children's teeth (for similar story, see Kuhn et al., 1988, p. 38). Sets of evidence from these studies conducted by scientists were progressively presented as shown in Table 1. The first two variables in the table were the causal variables and the second two the noncausal variables as perceived by the student and selected as described above.

TABLE 1
SUMMARY OF EVIDENCE PRESENTATION, EVIDENCE GENERATION AND COMBINATORIC PROCEDURES

Study			Evidence		Result
Number	Fluoride	Cost	Advertised	Pump	
	Evidence evaluation and predictions:				
E1	+	+	+	+	Good Teeth
E2	-	-	-	-	Bad Teeth
E3	+	-	+	+	Good Teeth
E4	-	+	-	+	Bad Teeth
P1	-	+	+	+	
E5	+	-	-	+	Good Teeth
P2	-	+	+	+	(Bad Teeth)
P3	+	-	+	-	(Good Teeth)

+ and - indicate presence or absence of attribute respectively.

Following the presentation of each set of evidence, the student was asked in turn "Does using toothpaste that has (the kind of variable) make a difference to how good the children's teeth are?" If the student's answer was based on her beliefs, this question was followed by the question "Do the findings of the scientists show that the (kind of variable) does make a difference or does not make a difference, or can't you tell what the scientists findings show?" Students were also asked how sure they were and why they answered as they did.

After four sets of evidence were presented, one causal variable (fluoride) and one noncausal variable (advertising) as perceived by the student had covaried with good or poor teeth and so no decision could be made as to their separate effects. One causal variable (cost) could be deduced as not having an effect, while the perceived noncausal variable could be shown to have no effect. To further evaluate the student's understanding of covariation and the effect of her beliefs on her reasoning, she was then asked to make a prediction from the evidence presented in P1 (Table 1). After presentation of the evidence in study E5, fluoride could be deduced as the causal variable and the presence of advertising as noncausal in accounting for good teeth in the studies. Two further predictions evaluated the student's understandings.

Evidence generation

To evaluate further the effects of the student's beliefs on her scientific reasoning, she was asked to generate the evidence that would be necessary to firstly support her strongly held causal belief (fluoride) and then her most strongly held noncausal belief (advertising) and then to generate the evidence that would be required to refute her beliefs about the same variables.

Combinatorics

To evaluate whether this student could readily conceive of all possible combinations of variables, she was also asked to present the combinations a scientist would have to test to cover all combinations of three of the variables used in the first part of the study for each context.

RESULTS

Evidence, evaluation and prediction

There was a high degree of consistency in the reasoning of Kate across the different contexts. For example, on presentation of evidence from the first study in each of the contexts (E1), Kate's responses to the effect of particular variables suggested some reference to the indeterminacy of the effects of single variables from just one set of given results. Her comments relating to the effect of the most strongly held causal variable for each context were:

- I'm not really sure because its also got high cost, advertised on TV and in a tube..... Its not singling out one thing, its just all different things together make the teeth bad (Toothpaste).
- It doesn't show that it alone did it but it says that A, B and C did it (Dry cleaning).
- Because it's not singling it out, there are no others yet to show that the square handle is why it got hot (Frying pan).
- The study doesn't really say very much yet but there are no others to show that the plastic is unreasonable (Conductivity).

However, when the evidence of further studies in each context was presented, Kate proceeded to make inferences about the effect of particular variables. In the dry cleaning and conductivity of rods investigations (laboratory context) she began making such inferences during the presentation of evidence at stage E2, whereas in the everyday contexts such inferences started to predominate at the presentation of evidence stages E3 or E4.

The predictions and questions relating to the effects of particular variables on the outcomes resulted in a variety of interactions between the student's beliefs and evidence. Initially, she was more likely to evoke a belief statement response in the toothpaste and frying pan investigations which related to the everyday context and in which beliefs would be expected to be more salient than in the laboratory contexts. However, when the belief response was followed by asking specifically what the results of the studies presented showed, the evidence based statements were predominant. For example,

> because plastic isn't as strong as wood and it would burn or get hotter easier

became on further probing,

> the plastic could be one of the things that made it quite hot because its here twice (pointing to results) that the plastic is there and the handle is hot (Frying pan).

In some responses, Kate mixed evidence and belief in her explanations. For example, on presentation of the evidence relating to study E5 in the toothpaste investigation, she commented,

> I think (fluoride) would make a difference because its a cleaning substance for teeth and in the study fluoride has resulted twice in giving good teeth.

At times, she accepted evidence contrary to her belief. For example, contrary to her belief of cost as a causal factor, she stated,

> It really depends on what sort of toothpaste it is and not on the cost, because up here (pointing) it's good teeth for high cost and low cost and down here it has the same.

At other times, her beliefs resulted in uncertainty and reluctance to accept the evidence presented. For example, she believed that whether a frying pan handle was solid or hollow would make a difference to how hot it became. In other instances, such evidence as that commented upon in the following utterance would be accepted as evidence of the variable being noncausal, at least when considered the variable was considered singly.

> It's fairly even. I'm not really sure because there is a hollow (in the handle) that has been hot and cold and a solid that has been hot and cold.

In most instances, the evidence statements describing the effects of a particular variable were principally based on a comparison of that single variable across multiple studies without reference to the presence or effects of the other variables in the study. For example,

> It doesn't really matter because there is low cost (toothpaste) twice and high cost with good teeth..... and there is also high cost and low cost with bad teeth.

There was only one hint of an appreciation of covariance, in the presentation of evidence in study E5 and in predictions P2 and P3 for the dry cleaning context. The covariance of substances A and C in the dry cleaning investigation was eliminated with the presentation of evidence from the study E5, allowing valid inferences as to the independent effects of these two variables to then be made. When asked for the effects of powder C, responses in this instance were of the form,

> Probably with powder A because you can see that there was no (powder) C and no (powder) A and it was dirty, and when there was C and A it was clean.

Yet, when discussing the effect of powder A for this same result,

> I think powder A would make a difference because when there was no powder A it was dirty and when there was powder A it was clean.

Just as for evaluating the presented evidence, Kate tended to focus on the variables one by one when making predictions, often ignoring some variables and giving an answer based on one of the variables only. In one prediction (P1 in conductivity rods), there was even a suggestion that predictions were based on a "sum" effect of all the variables rather than on a determination of whether judgements could be made about the causal or noncausal nature of individual variables.

> (Hot prediction). Because the shiny one has been hot twice and it hasn't yet proved it can be cool... solid I'm really not sure about because it has been going either way....but all the others added together would make it hotter.

Generation of evidence

When asked to present evidence to confirm her belief that fluoride in toothpaste was causal, Kate laid out the following evidence:

Fluoride, advertised, low cost, in a tube	good teeth

and remarked that

> It doesn't show yet, because you need another one really to prove that its right because if you just have one and your saying that it's good teeth, it doesn't really say fluoride alone makes good teeth.

She then presented further evidence,

No Fluoride, advertised, low cost, in a tube	bad teeth

and remarked when asked for her reasoning,

> If all the other three are the same and the one that had the fluoride in it was good teeth, then I did one with no fluoride and the other three the same, resulting in bad teeth.

Clearly, Kate indicates she has mastered inclusion and exclusion in this exercise, yet this was not apparent in evaluating evidence.

Interestingly, when asked to present the evidence which would prove that her belief was incorrect, she presented the following evidence:

Fluoride, not advertised, high cost, pump	good teeth
No fluoride, not advertised, high cost, no pump	good teeth

In each of the other contexts also, Kate varied two variables when trying to present evidence that would disprove her belief about the causality or noncausality of the variables. While mistakes were made in presenting evidence across the four contexts to support her beliefs, she was much more likely to be able to present evidence to support her beliefs than to disprove them. In some instances, efforts to disprove her beliefs resulted in her presentation of evidence that confirmed them.

Combinatorics

The frying pan variables were systematically laid out to correctly show all the possible combinations of three variables taken three at a time. In each of the other contexts, Kate adopted a similarly systematic approach but made small mistakes in omitting one case and/or doubling up on one case. It seems reasonable to assume from these results that the limitations noted in the previous sections were not due to an inability to systematically consider possible combinations, at least to the level of three variables.

DISCUSSION

To coordinate theory and evidence requires the ability to think about a belief or theory separately from the evidence that supports it and to be able to set aside those beliefs to assess evidence independently of those beliefs (Kuhn et al., 1988, pp. 219-220). Also, to think with those beliefs rather than just about them also requires that the student be able to consider alternate theories that might relate to evidence.

Kate was unable to do this on most occasions, mixing aspects of the evidence with her beliefs when called upon to evaluate the evidence presented. This suggests that for Kate, "evidence is equivalent to *instances* of the theory that serve to illustrate it, while the theory in turn serves to explain the evidence" (Kuhn et al., 1988, p. 221). She also interpreted evidence differently on occasions depending on whether the evidence presented was supporting or refuting her personal theory and was more likely to be able to propose evidence that supported her beliefs than she was for evidence to refute her beliefs. These findings suggest that Kate was unable to consistently differentiate theory and belief and to think with those theories in a metacognitive way.

In the evidence evaluation activities, Kate commonly made inferences about the effects of particular variables based on false inclusion, that is, inferring a causal relationship between a variable and an outcome based on evidence where two or more variables had covaried with the outcome. On observing instances where a particular variable and outcome covaried, she regularly inferred that such a variable was causal without regard to the possibility of covariation of other variables and often mixed evidence and belief to justify her conclusions.

Many recent instructional approaches take into account the student's pre-instructional theories and attempt to present students with data anomalous with those theories, attempting to bring about conceptual change towards the more accepted scientific theory (Chinn & Brewer, 1993). The results of this study and those of Kuhn and coworkers, point out that simply presenting such anomalous data may not lead to the expected results if the student is not able to differentiate theory and evidence and think metacognitively about their theories. This suggests that if such students are to benefit by such an approach and be able to rationally consider evidence in relation to their own and different theories, then a more determined effort needs to be made to develop the appropriate skills of argument in children. Further, Shauble (1990) has shown that the children who evaluated both their changing theories and the evidence from their investigations were most successful in understanding the phenomena investigated.

While some quite young children appear to be able to distinguish forms of beliefs and evidence (Sodian et al., 1991; Ash, Torrance & Olson, 1993) and the proportion of students displaying such skills increases with age, many adolescents and older persons are not able to demonstrate these skills. Importantly though, studies have shown that such skills are able to be developed by appropriate exercises (Kuhn, et al., 1992; Shauble, 1990).

CONCLUSION

This case study showed that the student did not demonstrate the thinking skills to adequately differentiate between her theories and evidence and that the scientific reasoning skills she employed were influenced by how the evidence related to the beliefs that she held. Such research has implications for our understanding of conceptual change and shows the importance of increasing our understanding of the process of change rather than just its content. In conjunction with the evidence from other studies, it also provides evidence that conceptualising science as argument, and developing the skills associated with that, may well have the potential for significantly improving science education. Further research will be needed therefore, to explore the development of teaching strategies for the enhancement of science as argument.

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THE RELEVANCE OF "RECENT AND RELEVANT" EXPERIENCE

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ABSTRACT

The importance of recent and relevant experience is being asserted for teacher educators though not others responsible for education policy and curriculum. The paper will review the "self evident" value of recent and relevant experience from the perspective of researcher/teacher educator returning to classroom teaching. The potential and implications for research on teaching and learning and the opportunities for more significant school experience in teacher education are outlined.

INTRODUCTION

The 1980s and 1990s were marked by a number of teacher education reviews and reports which yielded many consistent and well argued findings, but little significant action. Kozol (1992) described this preoccupation with reports and rhetoric as disguising "the fact that there's a vacuum of sincere intention" (p. 15). A more recent document (DEET, 1992) is based on the view that teacher educators have "obsolescent teaching experience" (p. 12) and need to show "a clear commitment ... to bridge the gap that has grown between themselves and contemporary classrooms ...." (p. 14)

The document asserts that there has been "a tendency to emphasise the academic content of studies frequently at the expense of a more professional and practical pedagogical orientation" (p. 16). Proposed solutions include using "outstanding seconded teachers" in education faculties, requiring "all teacher educators to spend at least three months in the classroom every five years" (p. 24) and developing pre-service courses which "make the school rather than the university the focus for pedagogical development" (p. 18). Without citing specific references, the DEET report embraces the UK response which has all preservice students spending two thirds of their training time in schools by 1994 and teacher educators required to obtain recent and relevant experience. The wider debate about these changes in the UK (e.g. Gilroy, 1992; Gunstone, 1989) is not acknowledged.

This paper addresses the matter of "recent and relevant" experience, exploring the assumptions underlying the idea and describing a personal experience which is recent and may be relevant.

THE MEANING OF "RECENT AND RELEVANT"

The desirability of wider relevant experience is not contested: the DEET paper is an outstanding example of the consequences of an inadequate understanding of the target for policy making. Recent and relevant experience for the writers may have assisted in producing a report more in tune with teacher education priorities and practice. Any person or group responsible for aspects of other situations would benefit from personal experience which leads to a deeper understanding and appreciation of the target group. This would apply to politicians, bureaucrats, community leaders and teachers in any area, so why the specific attention to teacher educators? This is the first of a series of questions that can be posed about the recent and relevant experience that is presented as a self-evident improvement for teacher education.

Which staff are most likely to benefit from what types of experience? School and classroom experience appear to be the major focus, as the argument centres on pedagogical reforms in teacher education. What proportion of faculty staff are engaged in teaching/learning/ curriculum studies in teacher education? It would be this sub-group (perhaps 25% of faculty staff at Monash) for which classroom experience would be most relevant. Would staff members with interests in administration, policy, economics, etc be welcome if they sought recent and relevant experience in the bureaucracy? The distinction between education, and the sub-set, teacher education, is blurred yet the charges of "obsolescence" are loosely directed at all working in education.

Which staff should engage in recent and relevant experience? Gunstone (1989) observes that the target at tertiary level in the UK ranged from those responsible for method studies to staff involved with any aspect of preservice education. He also concluded that "those who least need the experience are more likely to undertake it, and those most in need are more likely to avoid it" (p. 198).

How will "recent and relevant" experience lead to improvement? Assuming increased understanding follows experience in the school, how are these new insights and deeper appreciations to be conveyed to students? Capitalising on this rich experience requires a clear view about how students learn to be teachers. A revised series of "show and tell" lectures may make little difference and a major challenge would appear to be in arranging more relevant experiences for students. Gunstone (1989) points out that in the UK experience "It would have been far better for the quality of teacher education ... to have shown similar concern [as for school pedagogy] for the fostering and maintenance of expert pedagogy in teacher training courses" (p. 197).

Is there evidence that teacher educators have not kept up with developments in schools? The charge of being out of date could apply to many in education. The isolated nature of teaching means that a teacher with 20 years in classrooms could have one year of experience largely repeated 20 times. A principal often struggles to maintain contact with classroom issues and the bureaucrats and politicians, who make crucial decisions about administering, staffing and resourcing schools, tend to have very limited recent and relevant experience of schools. Many teacher educators can provide evidence of their efforts to maintain significant contact with schools and would be disappointed with assertions about "obsolescence" when they compare their knowledge and understanding with others who have equal or greater impact on schools. It could be argued that the most effective recent and relevant experience for teacher educators comes form close contact with a range of schools and an overview of school and system developments. The day to day contact in one school may not be as relevant as the UK and Australian thrust seems to suggest.

Who determines what is recent and relevant? McLaughlin (1987) points out that we cannot "mandate what matters". For teacher educators it has been difficult to arrange opportunities to gain wider experience in schools. Education is an academic field which does not allow for a clinical component within the terms of employment. Finding time for school experience must be done as part of leave, study leave or in addition to existing loads. Those seeking to mandate a "recent and relevant" condition will need to be clear about what will count and restructure existing employment conditions. They may be more advised to create a greater range of opportunities for teacher educators to gain relevant experience. There may be surprise at the number of teacher educators who will develop and implement proposals to seek quality experiences outside the university if conditions can be arranged.

CONSIDERING A PERSONAL EXPERIENCE

There are teacher educators who have made, and continue to find, opportunities "to bridge the gap between themselves and contemporary classrooms...." (DEET, 1992, p. 14). Some even find ways to return to teaching in classrooms in the face of considerable constraints. In one case, Newman (1992) returned to school to develop a research agenda grounded in the classroom concerns of teachers. In contrast, the teaching experience described in this paper was motivated by a concern to understand and evaluate teaching and learning ideas emerging from an intensive and extensive action research effort involving teachers and academics (Baird & Mitchell, 1986; Baird & Northfield, 1992). This teaching experience is with one Year 7 group and a teaching allotment including Science, Mathematics and Home Group. Unlike Newman (1992) my negotiations with the school were based on exchanging a teaching allotment with two teachers who would contribute to the preservice program. My first purpose in the school was to explore teaching/learning ideas and their impact on a group of pupils while still covering the syllabus and completing the assessment requirements of the school program.

A second purpose relates to a long term interest in addressing the theory practice gap in initial teacher education. For ten weeks the role of teacher educator became linkedwith that of a teacher when student teachers in my preservice group completed an extended theory/practice experience in the school. In this respect, in the return to school I had similar aspirations to Russell (1993) in making the consideration of school experiences a starting point for learning about teaching for both the teacher educator and the student teachers. The remainder of the paper will introduce a number of issues related to the researcher/teacher educator taking a teaching allotment in a secondary school and sharing some of the experience with student teachers.

SOME GENERAL REACTIONS

Two general reactions set a context for some more specific findings. Firstly, it is clear that in practice, my teaching falls short of my ideals and the vision associated with active and independent learning. My admiration for the teachers who have lead the way in closing the gap between practice and aspirations (e.g. Baird & Mitchell, 1986) is greatly increased. There are many questions about the reasons for the gap between ideals and practice and as a teacher educator you are forced to consider whether you are advocating ideas and approaches which are achievable in systems and schools as they presently function. The nature and reasons for this gap between aspirations and practice will be developed in more detail in the next section of the paper.

A second general reaction relates to the diverse range of research possibilities that become apparent in schools and classrooms. This is an observation also made by Newman (1992). A research background readily links teaching with a diversity of research questions. Addressing these research questions in a satisfactory way becomes an elusive challenge. Part of the difficulty lies in the need for a co-researcher to participate in data analysis. Personal journal records require a level of analysis by an outsider which leads to subsequent discussion and new insights. Data such as photographs taken by pupils to represent "learning and important parts of our classroom" require another person to interview the pupils. Their explanations and insights are less likely to be valid if their teacher probes the nature and reasons for selecting the particular photograph settings.

LEARNING ABOUT SCHOOL AS A SITE FOR LEARNING

As a person with a specific interest in encouraging more active learning in pupils, a first impression is that schools have a variety of functions in addition to encouraging learning. Schools are institutions with significant welfare and management functions. With a large number of one parent families and high unemployment, a large proportion of senior staff time is devoted to student welfare and gaining and maintaining conditions for student learning. Many features of schools act as constraints to learning and the author is teaching at a time of severe cutbacks which has limited the range of learning opportunities available for students (loss of enrichment and remedial programs, field trips, camps, sport, etc.). There is also a "dailiness" or routine in school life which means that "academic" learning is only part of what schools offer students.

LEARNING ABOUT THE PROMOTION OF ACTIVE LEARNING AMONG YEAR 7 STUDENTS

A number of established principles related to promoting more active independent learning are vividly demonstrated in the classroom context.

- Active learning requires learner consent. By Year 7 level, students have not often experienced teaching and assessment approaches designed to encourage thinking and risk-taking in the learning process. It is not easy to convince students of the benefits of engaging in activities which require divergence rather than convergence on right answers. There is a clarity and comfort for students (and teachers) in transmissive procedures and right answers. The importance of self confidence, trust (Baird & Northfield, 1992, p. 92) and support from teacher and among class members is well underlined as one strives to establish the fragile classroom environment to support active learning. The benefits for students are not self-evident to them especially when different learning outcomes are being valued by one teacher.

- Much of the content and curriculum materials in school science assume convergent passive learning. This combined with a feeling that the first active learning experiences should be associated with successful outcomes, and be assessable, meant that there was some tentativeness in initiating activities. Intellectually demanding activities need to be used sparingly among more routine tasks and their outcomes and purposes reviewed carefully with students.

- Little progress will be made if the introduction of different teaching strategies occurs in limited ways for students and teachers. The isolating nature of teaching acts as a constraint and it is significant that major progress has been made when teachers have created conditions to learn together (Baird & Mitchell, 1986; Baird & Northfield, 1992). For students, experience with different learning demands should occur in different subject areas if their learning experience is to be regarded as more than an atypical teacher in action.

- The issue of class size becomes important when employing teaching strategies intended to promote active learning. It is easy to initiate responses from a proportion of students and gain satisfaction from the overall impact. Extending opportunities to the less confident, less motivated or more reserved students, requires making contact with each student and such a concern for learning for all is not always part of the debates about class size. The number of students which can be managed from a teaching/passive learning perspective is larger than the size of the group if quality learning for all students is a primary focus.

- Understanding the classroom culture and context is a key to the successful introduction of more intellectually demanding activities. After an earlier teaching experience I formed a hypothesis that students who made greater progress in their learning skills were those in stable peer group relationships. Understanding the social norms and peer group relations in a classroom appeared to assist in interpreting student responses to classroom activities. The pattern of relationships with the present group of students is still being understood, but it is already clear that self confidence and the consent of students are crucial for improvement in learning. It is also clear that interventions designed to improve active learning increase the spread of student performance. This underlines the importance of building self confidence, trust and making sure the assessment places value on what students are being encouraged to do.

ADDRESSING THE THEORY-PRACTICE GAP IN PRE-SERVICE TEACHER EDUCATION

The opportunity to be teacher and teacher educator with student teachers for ten weeks in a school setting created many possibilities. Only a few of these possibilities were developed. Experience with the school-based program in previous years had indicated benefits for student teachers in experiencing a wider range of a teacher's responsibilities and taking classes for complete topics. We realised that it takes at least three weeks for student teachers to include class and pupil characteristics in their lesson planning. We also realised that there is a fine line between the school experience being a socialisation process rather than an opportunity to effectively learn about teaching.

Teaching in the school meant that student teacher and teacher educator were able to plan, implement and review classroom experiences together. This common teaching episode allows for discussions to be based on the "authority of experience" (Russell, 1993) with theories emerging which are grounded in a shared experience. The requirements for student teachers to give, rather than just receive comments and advice, places active learning demands on the people learning to be teachers. They find they need "theories" to communicate their ideas and reactions.

As with the researcher in the teaching role, the teacher educator becomes confronted with a very rich and complex environment for learning. Student teachers are easily overloaded as they begin to respond to all the possibilities that exist.

MAKING RECENT EXPERIENCE RELEVANT - CONCLUDING COMMENTS

The interest in recent and relevant experience for teacher educators misses the point in two important respects. Firstly, it has proved difficult to arrange experiences in school settings and a great deal of change is needed to provide opportunities for those who wish to gain wider experience. Secondly, the connection between relevant experience and improved teacher education programs is not clear and a clear rationale for the way students learn to be teachers appears to be a prerequisite for subsequent improvements.

The return to teaching has lead to important personal reflections:

- There is a gap between aspirations and what can be achieved in the classroom. This is an inevitable outcome of the diverse and changing role of schools. The traditional separation of research and practice leads to simplified perceptions of each others work and explains why the limited communication approaches between the two groups tends to fail. As teaching is considered from a research perspective the interdependence of research, theory, practice and context become obvious. What counts as knowledge and characteristics such as generalisability take on a different meaning in the unpredictable, complex and unique contexts of schools and classrooms. This does not mean research has no contribution to make to schools, but that teachers require the conditions to gain a personal understanding of the ideas for their own settings.

- The opportunity to be teacher educator and teacher in an extended school based preservice program opened up an overwhelming range of possibilities. The challenge is to develop a coherent program which capitalises on the school experience and concentrates on the most promising opportunities without overloading student teachers.

Recent and relevant experience has the potential to be valuable but whether we are able to take advantage of this potential remains problematic. My recent experience has created more questions than answers and a great deal more time and reflection is needed to capitalise on the value of this experience.

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ACTION RESEARCH THROUGH STIMULATED RECALL

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ABSTRACT

The emphasis in classroom learning research has moved from process-product models to the mediating process paradigm. The stimulated-recall interview and think aloud techniques are the two main processes that have been used in attempts to find out what goes on inside students' heads while they are learning. For example, this researcher has used the stimulated-recall interview technique to identify the workplace thinking of a marine science researcher, and the in-class thinking of a year eleven biology student. Such studies as these have produced findings with important implications for the classroom teacher in the role of action researcher. This paper describes how to conduct stimulated-recall interviews and discusses some classroom implications from the two studies.

INTRODUCTION

How can one gain access to what students are thinking in the classroom? I have been a science teacher for eighteen years and this question has always fascinated me. For instance, over this time there have been many occasions when students have obtained correct answers to problems but have not been able to explain their reasoning. Also, there have been many students who have seemingly understood concepts very well but have failed process questions in exams. These observations, together with the emphasis in Australia and elsewhere on producing thinking students for a 'clever country', have attracted me to research the thinking of science students in the classroom.

Gardner (1991, p. 6) is very challenging when he suggests that maybe the entire educational system is fraudulent as "the gap between what passes for understanding and genuine understanding remains great." Costa (1991, p. 31) cites Hart (1975) who describes schools as "brain incompatible." Costa goes on to state that studies of creativity undertaken by such researchers as Ghiselin (1955) and Gardner (1982) "find that what young children do prior to entering school and what practicing scientists and artists do is more similar than anything that goes on in between" (1991, p. 31). An investigation into the workplace thinking of a research scientist supports these findings. When questioned by the author about her recollections of school science, the research scientist's response was not too encouraging:

> Science at school is pretty boring and it's basically textbook stuff. I was good at it but only because I'm a good rote learner and things like that, good memory.

An investigation by the author into the in-class thinking of a year 11 biology student, who performs at a high standard in the subject, also raises some concerns. For example, during a practical class her thinking started off positively, but with time she became frustrated and concluded "...it was more like a waste of time". While she pointed out that not all the practicals were like this, she did not rate practicals very highly in terms of requiring her to think. This is worrying as practicals are a critical component of the biology course. Later, the student stated that she would like the opportunity to investigate some of her own problems in biology. Perhaps more ownership of the biological problems under investigation would lead to a more enthusiastic response from the students.

Gunstone and White (1980, p. 43), in a study involving first year physics students at Monash University in Australia, conclude that these highly successful secondary school students "...had lots of physics knowledge to hand but were unskilled in seeing which bit applied to the given situation". Tobin and Gallagher (1987) found that Australian high school teachers were mainly concerned with covering course content on time. Further, they found that classroom activities focused on rote learning of science facts and formulae. Experience suggests that teachers reluctantly teach school courses which are overly content and assessment driven and findings from the year 11 biology student study support this.

Studies conducted in England by Shayer and Adey (1990, p. 267) conclude that among 16 year olds "only 11% showed the mature formal operations needed, for example, for university work in science or mathematics". These findings raise questions about the level of thinking required of students in the learning and assessment of school science. Edwards (1991, p. 91) outlines a further concern when he concludes: "what students are thinking about during classroom instruction is far removed from the type of thinking teachers expect and want". It is proposed that if we as teachers wish to nurture more meaningful learning in our students we need to obtain more direct knowledge about how our students think.

Perkins (1992) differentiates between knowing and understanding. He proposes that we can determine whether a student knows Newton's laws very easily by asking them to write out the formulae. But he questions how we as educators know if a student understands Newton's laws. He suggests that his students could be showing him "'canned' performances with hardly any understanding of what the laws really imply or explain or why they are valid" (p. 76).

Two techniques which attempt to identify the cognitive processes involved in teaching and learning are the think aloud protocol and the stimulated-recall interview. The think aloud technique does not readily lend itself to classroom research as it can cause an unacceptable level of interference. Also, it is argued that the use of this technique with a number of students in isolation is too far removed from the naturalistic setting of the classroom. Marland (1984) discusses the importance of a naturalistic setting in classroom cognition research.

Stimulated-recall can be used to access the in-class thinking of a student during a post-lesson interview. The student's recall of in-class thinking is stimulated by viewing a video which shows a split screen image of both the student and the teacher, and the general functionings of the classroom. For example, much stimulated-recall research by Edwards and Marland (1982, 1984a, 1984b) has given insight into the in-class thinking of students. One study looks at the thinking of four senior biology students. In this study, they concluded that "...after careful reading of the literature ... we were convinced that stimulated-recall offered us the best route to accurate data" (Edwards & Marland, 1982, p. 40). The stimulated-recall interview technique will now be discussed.

THE STIMULATED-RECALL INTERVIEW TECHNIQUE

It is suggested at the outset, that one should become familiar with the many assumptions that underlie the use of the stimulated-recall technique (Marland, 1984). One of the first to report on the use of stimulated-recall was Bloom in 1953 (cited in Calderhead, 1981). Examples from classroom cognition research include: Morine and Vallance (1975), Clark and Peterson (1976), Marland (1984), Edwards and Marland (1982), Marland and Edwards (1986), Mitchell and Marland (1989) and Okamoto (1992).

Following is a practical summary of how the stimulated-recall interview is set up and conducted, together with examples of how it can be used. This technique gives the classroom teacher the opportunity to become an action researcher. Who better to study the processes of thinking in classroom learning than the people at the workface. Winter (1989), when speaking of action research in teaching, proposed "...that the process of understanding must start from reflection upon one's own experience, and the sort of 'wisdom' derived entirely from the experience of others is at best impoverished, and at worst illusory" (p. vii). Stimulated-recall interviews can provide the setting to facilitate the reflective process.

The stimulated-recall technique will be summarised under six phases:

Phase 1: Selection and preparation of the research subjects
Phase 2: Preparation of the video recording
Phase 3: The video recording
Phase 4: The stimulated-recall interview
Phase 5: Typing of interview transcripts
Phase 6: Analysis of the data

Phase One: Selection and preparation of the research subjects

Following is a list of pointers that have been useful when selecting and preparing the subjects for the stimulated-recall interviews. These pointers are based on the work of Edwards and Marland and personal experience. It is assumed that a classroom teacher with assistance from a workplace colleague, could research the thinking of students from his/her class. The classroom teacher will be referred to as a classroom action researcher.

- The classroom action researcher should reflect upon the preferred teaching strategies that he/she uses, the preferred learning styles of the students and students who could possibly participate in the study.
- Approximately two weeks from the start of data collection have the workplace colleague conduct individual interviews with research subjects (i.e. those students who will be videoed during a lesson and later interviewed about their thinking during the lesson) to ascertain which students would be best suited for the study. Typical questions for the preliminary interview could be: What is your name? Which subjects do you enjoy the most at school? How would you rate yourself as a thinker? Try and think of a problem you have had in your (History, Science, English, etc.) class recently - how did you go about solving it? It is most important that the selected students: have an ability to articulate their thoughts; are able to express their ideas with clarity; are willing to be frank about their thinking; are prepared to spend time being interviewed; and, show a preparedness to be videotaped in the classroom. A brief fifteen minute interview with each student should answer most of these questions. Ensure, as far as possible, that the selected research subjects are representative of the target audience for your study. A cross-section of such variables as academic achievement, ability, motivational level and gender could be used as a guide in selecting which students could be the research subjects, but this will be largely determined by the aims of your study.

- It is usual to select between two and four students as research subjects for the study. The number of students depends upon the amount of time available for the study and the resources at hand.

- Prior to the commencement of videoing, have the workplace colleague establish further rapport with the selected research subjects so as any perceived threat can be lowered. The workplace colleague should assure the research subjects of general anonymity beyond the school personnel involved. As the workplace colleague will conduct the interviews, permission should be sought from the research subject to allow the classroom teacher (classroom action researcher) to hear a tape of the interview at a later time. It is important to discuss the process into which the research subjects are about to enter as their cooperation is critical to the successful completion of the study.

- In the days leading up to the data collection, all the students in the class need to become familiar with the presence of the workplace colleague, who could also be the video camera operator. At least one of these lead-up lessons should be videoed in a 'dry run' so as all students can become more accustomed to the cameras. It is also an opportunity for the camera operator to become familiar with the setting up in the classroom. The 'dry-run' video is not used in the study.

Phase Two: Physical preparation of the room for the video recording

Two cameras are set up in the classroom. One camera is used to video the teacher and any other major instructional resources (e.g.. video, slides, overhead projections, blackboard, experiment, group discussions) and the second camera is used to video the research subjects.

A video mixer is used to produce a split screen image which will allow the research subject to view both the teacher and him/herself at the one time. A remote microphone is placed in a position such that both the teacher and the research subjects can be recorded.

Phase Three: The video recording

The number of videoed lessons is largely dependent upon the availability of resources, time and the variety of strategies used for teaching/learning in the science discipline. For example, in the year 11 biology student study, the videoed lessons were a teacher-directed group work lesson, a transmissive teacher presentation, and a student practical in pairs. Time constraints and limited resources only allowed one research subject to be used in this study. A pre- and post-study interview with the student, together with the three lesson interviews, made up the complete set of audio taped interview data.

Experience shows that the study usually involves videotaping about four lessons over a two to three week period. The resources and time required for such a study would include four videotapes, two 90 minute audio tapes per research subject and enough time to conduct four 45 minute interviews with each research subject.

Phase Four: The stimulated-recall interview

One of the major threats to the validity of this type of data is in the stimulated-recall interview procedure. It is wise for the workplace colleague, and not the classroom action researcher, to conduct the interviews. It is proposed that such a person can act as a neutral third party and allow the research subjects to be more open with their comments. It is critical that the interviewer is aware of how to conduct stimulated-recall interviews and is able to conduct the interviews soon after the recorded lesson. Kagan et al. (1967) outline a list of procedures for Interpersonal Process Recall (IPR) for counselling and these procedures provide a useful basis for stimulated-recall research in the classroom (Marland, 1984). The following guidelines, based on procedures suggested by Marland and Edwards (1986), Marland (1984) and Spradley (1979), have worked well for this researcher.

- Before the first interview, check once again that the research subject understands the purpose of the research study.
- Create a relaxed setting for the interview in a closed or separate room.
- Interview each student separately, one on one.
- Each interview to be about forty-five minutes duration.
- Encourage the research subject to press the video recorder pause button and self report on their thinking as much as possible. You could encourage them to say whatever is on their mind, to not hold back any hunches, to speak as continuously as possible, to speak audibly, to not worry about speaking in complete sentences, to not over explain or justify what they have said, to control the interview as much as possible, and to elaborate as much as they like.
- Actively listen to the research subject and respect what he/she says.
- Respond to the student's self reporting with encouragement and invitation for further disclosure.
- Whenever necessary request further clarification or confirmation.
- Avoid leading questions, making evaluative comments or being critical (e.g. "You smiled there, did you now understand how to calculate the density?"). Also, avoid leading the interview by the inappropriate use of non-verbal behaviour.
- Initiate student self reporting if and where necessary by asking such questions as: "What were you thinking just then?" or "What are you saying there?"
- Audio tape all stimulated-recall interviews.

Phase Five: Typing of the interview transcripts

If an analysis of the interviews is planned, typed transcripts of each interview will be required. However, this involves much time and/or expense and does not need to be done if only a casual inspection of what was said is required. It is suggested that for the classroom action researcher enough can be gained from simply listening to the interviews and reviewing the lessons.

Confidentiality must extend to the classroom action researcher being able to listen to the audio tapes. The research subjects can be given the option of removing any statements made by them before their classroom teacher/action researcher listens to the audio tape. This researcher has found that if the research subjects are approached in a sincere and professional manner, they are willing to allow any people concerned with their learning to have access to the interview tapes and/or transcripts.

Phase Six: Analysis of the data

Usually, the classroom action researcher may wish to conduct only a casual analysis of the data by listening to the audio tapes of the interviews. This approach is sufficient for identifying the types of thinking used and preferred by the research subjects. The classroom teacher (classroom action researcher) could utilise these insights in a number of ways. For example, the teacher could (a) make more use of those teaching approaches that effectively engage students in thinking, (b) identify weaknesses in a student's thinking ability, (c) be informed as to which specific thinking skills could be taught to individual students, and (d) become a more reflective practitioner.

CLASSROOM IMPLICATIONS

While stimulated-recall interviews have been mainly used by university researchers to identify the in-class thinking of secondary school students, the time has come for the classroom teacher to more willingly adopt an action researcher role. The stimulated-recall interview process provides a medium through which the teacher and student can interact, using first hand data, with thinking as the focus for discussion.

Over time, the variations in the predominant thinking styles of different students in different year levels, and across different disciplines, could be identified. This can provide valuable insights for teachers when considering which teaching strategies are more efficient at enhancing the thinking and learning of different individuals or groups of students. Also, it prompts metacognition (see Baird, 1986) in participating students. Students, often for the first time, are introduced to a method whereby they can reflect on the ways in which they think.

In recent investigations the stimulated-recall interview technique has been used to identify the thinking of a research scientist and a year 11 biology student. Data from these studies allow comparisons to be made between the types of thinking that are predominantly used by each, and provide valuable insights into more effective approaches to science teaching in schools. Some issues arising from this research will now be briefly discussed.

It was found that while the research scientist basically worked towards finding answers to her own questions, and was excited about the new questions that the answers would raise, the year 11 biology student was given little opportunity, if any, to pursue answers to her own questions through laboratory investigations. The student indicated that while she liked practical work and would like to investigate some of her own questions, she did not need to because "...at school we've always been given a textbook". It comes as no surprise that she did not rate the practical very highly in terms of requiring her to think. On the other hand, the research scientist was very enthusiastic about her practical work:

> I started looking at these samples under a microscope and I wouldn't say it was a flash or revelation, but seeing all this ... and everything, I realised that what I had here was a potential link in the detrital cycle on coral reefs.
>
> ... and then I thought , 'Wow, I'm forming a little part of this big picture'. I felt really, really thrilled about this and thought that this was a really good discovery. So, that kept me on a high for two weeks.

As noted earlier, the research scientist did not show much interest in school biology, and indicated that for her there was too much rote learning. She described it as "pretty boring" and "basically text book stuff". She had certainly changed a lot since school.

> The field I'm in, biological sciences,.....basically we did the Web of Life. It was boring and it was easy, and it was so simple to get a good mark in that, that it was ridiculous. I never even considered biological science when I left school as a career. That's how dull I found it. That's what I mean by straight text book stuff. It was almost like the teacher got up in the front of the class and was reading from the text book. May as well have been.

While the research scientist was very willing to take risks and even to guess if she couldn't predict an outcome, the biology student did not share the same enthusiasm for finding out, and she did not seem to be very willing to take much risk at all:

> I was just asking which one was salt and, I mean I thought I knew but I just wanted to get someone else's opinion, make sure I didn't make a mistake.

Perhaps if the biology student had an opportunity to investigate her own questions or even had been required to formally predict what she thought would happen in the set experiment, she would have had more ownership of and interest in the investigation. The biology student did have expectations, but she herself did not seem to take them too seriously. Interestingly, both the scientist and the student used similar analogies when defining science – the student described science as a puzzle and the research scientist described it as a crime investigation.

The research scientist saw herself as the planner of the experiments, and the biology student saw experiments as something she found in her textbook. It is suggested that the workplace thinking of research scientists is a good indicator of some types of thinking that could be nurtured in school science. Somehow the excitement and curiosity seemed to be lacking from the biology student during the practical class. It was just another piece of work to complete as opposed to an inquiring path towards discovery.

The research scientist spoke of 'intuitive flashes' and the 'thrill of discovery', and always being aware of and open to the possibility of a connection between concepts being made. It seemed that once the fertile, cognitive base had been laid by her readings, discussions and investigations, she was keen to predict possible outcomes. She would then be prepared for when the right connection was made between different concepts in her mind, which she likened to a spider's web. Maybe the student needs to be nurtured to have more patience and excitable curiosity. The exciting things do happen, but they occur infrequently and inconspicuously.

CONCLUSION

The stimulated-recall process is relatively easy to use and the information it provides is both diverse and rich. Staff in-service programs could be developed to inform teachers of how to use the stimulated-recall interview technique with their students. Teachers could work in teams to help each other identify the types of thinking that work best for their students. Maybe teaching could shake the tag of being "the second most private act" (Costa, 1992). If necessary, resources could be made available to encourage staff to build up thinking profiles of their students. Such profiles could provide valuable diagnostic feedback on the types of thinking that individual students employed successfully or were lacking. Perhaps students who do not successfully demonstrate an ability to use particular types of thinking could be taught specific thinking skills.

At a time when classroom practices worldwide are under the microscope, and the demands for school leavers to have the ability to think is reaching a crescendo, the simulated-recall technique provides an efficient method for identifying the in-class thinking of students. Also, much can be learnt from the successful thinking of workplace professionals. This in turn can be used by teachers to make classroom experiences more relevant and thought provoking. Maybe school students could even be given an opportunity to do some real research of their own in school science.

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AN ALTERNATIVE MODEL FOR TEXTBOOK FORMATION

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ABSTRACT

My Masters research project is a discourse analysis of physics textbooks. I am using the term 'discourse' in its sociological sense rather than its linguistic sense. I have interpreted my endeavours to date as showing that there is a basic confusion underlying the writing of textbooks. Whilst authors believe that they are revealing the universe to the student/reader, they understand tacitly that more is required than just revelation. I wish to argue that the 'more that is required' would be more readily constructed by authors if they understood that what they are doing is arguing a case: a case that scientific knowledge is an effective and appropriate way of interpreting the world.

INTRODUCTION

This article is the result of work carried out for a Master of Education thesis. The thesis topic is *A discourse analysis of physics textbooks*. The research carried out enabled me to deconstruct the discourse of the physics textbook and identify some of the processes acting between the authors and their writing in the formation of physics textbooks. Whilst it is one thing to offer a critique or deconstruction of something it is quite another to offer an alternative. This article is a preliminary attempt at offering an alternative. It is acknowledged that this alternative may not be viable given the institutionalised constraints that act within education and within the publishing industry. However, alternatives are necessary before change is possible. This is the motivation behind this paper.

THE ALTERNATIVE MODEL

The alternative model put forward in this paper has been structured on the basis of certain assumptions. These assumptions are that the belief held about the nature of knowledge by teachers and authors will determine the learning theory or theories followed. These in turn will determine the pedagogy adopted and this will contribute significantly to teaching and the writing process and product of, in this case, physics textbook authors. For example, if one believes that knowledge is discovered (in the simplistic sense of this word) then a transmission model of learning and its associated pedagogies would most probably be adopted, these would encourage an author to tell the reader, that is, present the rhetoric of conclusions. Alternatively, if an author believed that knowledge was constructed by scientists as a result of contextually bound discursive and social processes, then the learning model is more likely to produce to an interactive teaching model or a constructivist teaching model and the pedagogies that the author translates into the textbook writing will be very different.

The belief about the nature of knowledge that lies beneath the alternative model proposed in this paper is that scientific knowledge is constructed by rhetorical (persuasive) processes of interaction between scientists until consensus is reached. This belief is based on research into the history of science and the sociology of science (Kuhn, 1962). The knowledge becomes immortalised to some extent and the process of its rhetorical construction is 'forgotten' in the interests of efficiency (Woolgar, 1988, Brackenbridge, 1989). This convenient amnesia decontextualises the knowledge and enables the knowledge to be recontextualised inside the discovery myths that abound in physics textbooks. (Factor & Kooser, 1981) If knowledge is rhetorically constructed by scientists then the nature of the knowledge to be taught/learned in science education should contain elements of that process. If it is not included then, by default, the discovery mythology is reinstated.

The learning theory that is compatible with this view of knowledge is social constructivism (Glasersfeld, 1991, O'Loughlin, 1992). Students construct their understanding in the light of their prior knowledge, their experiences and through a discursive process involving their peers and their teachers. The discursive process ideally results in the student acquiring particular scientific knowledge. In science education the intention is not that the student constructs their own idiosyncratic view of the universe but that the student comes to understand the concepts and theories that have been reached by scientists after the discursive (rhetorical) processes they have undertaken. The view of the universe constructed by students should match the accepted scientific view. The students will need to be persuaded to accept this scientific construction.

Textbooks, teachers, syllabus writers and so forth must persuade the students of the correctness, appropriateness and plausibility of the accepted body of scientific knowledge. Stinner (1992) has a very clear set of criteria for arguing that case around the issues of the comprehensibility, plausibility and usefulness of the scientific concepts. The grounds put forward in the argument are that there is evidence for the theories and concepts, they have clear definitions, they have predictive power and explanatory capacity. The knowledge can be applied instrumentally and has interconnections to other knowledge. Stinner gives several examples of concepts and theories and the support in favour of them - their definition, the evidence for them, the diverse connections to other things, their capacity to enable predictions to be carried out and their exemplification. He claims that the presentation of the knowledge with this soundly argued support is more persuasive and effective than just telling the students or only **partially** arguing through the case for the material.

In both this pedagogical approach and more orthodoxly described constructivism, it is very important that the nature of the audience (the learners) and their prior knowledge be understood. An incorrectly assessed audience can result in the argument going past the audience completely. In both constructivism and this rhetorical approach it is possible to define the audience. That is, to attribute characteristics to the audience that they thereby acquire or behave as if they have acquired.

Interpretations of Author-Talk

The implementation of any alternative requires that the current situation be understood so that the nature of the changes from current practice that are required can be identified.

The author interviews undertaken as part of the Masters thesis referred to earlier have been interpreted in the light of action theory as discussed by Kemmis & McTaggart (1983). All actions, including textbook writing, are guided by a combination of explicit beliefs and tacit assumptions. Contradictions between these assumptions can produce actions that do not match with explicit beliefs. In this case the contradictory action is writing books that consist of more than just telling, just *un*covering the knowledge. There was a tacit understanding that 'more' is required.

The interviews indicated a lack of understanding about what the 'more' required might be. The authors knew what they didn't like about other texts and they endeavoured to address those dislikes. However their attempts at supplying the something extra was otherwise very vague.

Examples of the comments they made are as follows:

> I think the main thing about the book that I like is that instead of being an average textbook that sort of summarises the physics and gives some examples, the book actually tries to teach and I think that's a little unusual and that's one of the reasons why it's wordy ... A lot of books don't explain it at all they just state it. (Author 4, p.4)
>
> This contextual approach is completely new in the sense I don't think I've read or seen anywhere except in odd journals ... how do you go about trying to grab the real world of physics in the classroom ... there are no exemplars ... so the influence was there to try and see what these research papers and other sorts of good ideas ... how they could incorporate all that into a textbook - that was the big challenge, a very difficult one. (Author 2, p. 11)
>
> We tried to write it to give the student a student reference as well as a purely teaching text ... in ten years time they could still flick it open and make sense of it. (Author 1, p.9)
>
> I wrote to try and use the problems as a way of getting the students to ... to use the intellectual tools and get them to make sense of the [ideas]. (Author 3, p.2)

The tacit understanding held by (some of) the authors is possibly akin to acknowledging the validity of the social constructivist learning model in as much as they come very close to saying that the student readers need to be persuaded. This interpretation is supported more strongly by the comments the authors made specifically concerning the student readers:

> ... we were trying to make it less formal, more personal for completely different groups of students ... (Author 4, p.8)
>
> I was probably [writing] more as a conversation between myself and the students as individuals rather than a group. (Author 3, p.13)
>
> ... we really wanted to have a book that presented physics without pulling punches and so on and that was intended for the capable type of student. So in a sense we weren't really saying this will cover every student's needs, we don't think it does ... (Author 2, p.8)
>
> ... that's part of the reason we were trying to make it attractive to students, by using lots of photographs and diagrams and tables of ... interesting data of, I suppose, what we consider interesting data to people... (Author 2, p.8)

In all except the second quotation here, it is possible to see the authors defining their readership. They are making assumptions about the readers.

Textbooks as persuasive documents already

Many textbook researchers indicate that current textbooks are persuasive (or rhetorical) but contain inadequate arguments. They persuade through the use of the authority of the text-teacher-author combination (Olson, 1989). They selectively exemplify generalisations, they repeat their content and they present the knowledge within a discovery mythology (Factor &

Kooser, 1981). This poor rhetoric succeeds because of the support given by the institutionalised processes of schooling through the nature of assessment and the uniformity of education across societies and time.

Examples from the textbooks studied are as follows:

> Alpha particle radiation involves the ejection of two neutrons and two protons ($^4He_2$ or $^4\alpha_2$) from the nucleus of the radioactive element. (Book 2, p.155)

> Rutherford studied the nature of the radiation. He found one radiation that was easily absorbed (he called this type of radiation α-rays) and another type ... Rutherford, by using techniques similar to those employed by Thomson, was able to determine the charge to mass ratio for α-particles ... Further experiments in which α-particles were collected in an evacuated space enabled the particles to be identified as the nuclei of helium atoms. (Book 1, p. 555-556)

The first quotation endeavours to argue on the basis of the authority of the text-teacher-author combination. The second quotation combines those grounds with an allusion to the authority of science (by reference to Rutherford and Thomson) and enmeshes the information in a version of the discovery myth. The use of the words 'found', 'determine', and 'identified' are synonyms of discovered. There is an inference that what Rutherford did was completely obvious and that deduction and theoretical interpretation played no part in the process.

Applying the alternative model

Whether one assumes that textbooks currently just tell or that they argue on poor grounds, the application of the alternative model being advocated here requires that authors (preferably teachers also) acknowledge that they are involved in a process of argument (they are arguing a case). The textbooks must contain arguments that are more persuasive than those currently in use. Stinner's grounds are more valid than those mainly employed currently. If the authors were to acknowledge that writing a book requires them to argue a case then they would become aware of the weakness of the arguments they are presenting at the moment.

Stinner (1992) and Arons (1990) both claim that textbooks are most deficient in their presentation of evidence. If evidence is to be provided as part of an argument then there are many forms it could take. Some forms might be evidence for and against the concept or theory, the historical sequences leading to the construction of the ideas, the theoretical context of that time, mathematical derivations, original experimental work (data and interpretations), redesigned classroom laboratory work and so forth.

An example of some possible evidence for the previous discussions about α-radiation is provided by Arons (1990). He describes an experiment carried out by Rutherford which provided a piece of the puzzle concerning α-particles. The embeddedness of this evidence in the theoretical context of the time is very clear.

> Radon gas, obtained by pumping it away as it emanates from a radium compound, is placed in the inner, extremely thin-walled (0.001 cm) glass tube. This tube is sealed within a larger heavy-walled evacuated tube. The α-particles from the decaying radon have enough energy to penetrate the thin-walled tube but are trapped in the thick-walled outer container over a seal of mercury. After a sufficient period of time (about a week), enough gas accumulates in the outer container to allow a spectroscopic test. Additional

> mercury is let in to compress the small amount of gas into the capillary, which is fitted with electrodes. Electrical discharge between the electrodes causes emission of a line spectrum from the trapped gas. Rutherford and Royds reported positive identification of the helium spectrum and thereby settled the question as to the identity of α-particles. (p.241)

The VCE Physics course (and the VCE science courses in general) show improvement in the area of diverse connections though social context consideration but the social consequences of applications are not treated strongly. The translation across to textbooks is variable and in other states and countries Stinner's diverse connections category is very thin in many books. This thinness is not defensible if it is noted that the **reason why** the knowledge is being presented to the students is located in the diverse connections category. The instrumental value of the knowledge is associated with its applications and the social impact of those applications.

An example of a diverse connection for α-radiation, taken from an unpublished manuscript by S.E. Freeman on the biological hazards of plutonium, could be the following:

> The biological hazards of plutonium relate primarily, if not indeed exclusively, to its radioactivity. All the isotopes of plutonium are radioactive; most are alpha emitters....
>
> Because of the short range of alpha particles there is no danger to people from external radiation. Plutonium in direct contact with the skin will only penetrate the epidermal layer, which is continually replaced after injury. Thus plutonium must enter the body to be harmful. Entry may be through a cut in the skin, via the lungs or after ingestion ...

Associated with arguing the case for the scientific knowledge, there will inevitably be a parallel argument around the issue of the need for the students to know these ideas. The diverse connections of the knowledge provide the material for that argument.

Acknowledgment that one might not convince the reader should encourage the authors to find out about their readership and not define it in their own image or in a familiar image. Acknowledgment that the task is one of arguing a case requires that one believes that the readership can understand the argument and do not have to rely blindly on authority. The above description of Rutherford's work by Arons would presumably be reworded for a secondary school level audience but the simplicity and elegance of Rutherford's logic would remain.

CONCLUSION

The belief that knowledge exists out there to be uncovered leads to the transmission model of teaching. The belief that knowledge is constructed and legitimated socially leads to another type of pedagogical process. Given the support for the social constructivist learning theories, this paper presents the argument that the appropriate pedagogy is one that makes the construction processes explicit and reconstructs the knowledge as plausible, fruitful and understandable. This is a rhetorical process - the textbook writer is arguing the case for the acceptance of the concepts of science. Learning is a process of construction by the individual in a social environment. Such a style of writing shows greater respect for the reader. The outcomes of successfully arguing the case would be better understanding of the concepts and theories and a better understanding of the nature of scientific knowledge.

A textbook written such that the case was argued to the depth indicated here would not cover the number of concepts and theories currently included in physics syllabi and textbooks. Nevertheless, the students would know more about the material including the status of the knowledge - they might even be scientifically literate (Kuhn, 1993).

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HOW CONSISTENTLY DO STUDENTS USE THEIR ALTERNATIVE CONCEPTIONS?

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ABSTRACT

Existing research indicates that many students hold an alternative conception that "an object in motion must have a force pushing it along", but they do not apply this conception consistently to problems involving different types of motion. This project was designed to investigate the degree of consistency of student responses to questions concerned with linear motion. The results indicated that most students were unable to consistently apply either the alternative conception or the correct scientific response. The students appeared to have a general problem in recognising similarities between contexts, even when the contexts were closely related. The results also suggested that the responses of some students were influenced by contextual factors such as the nature of the moving body, the direction of the motion and the speed of the motion.

INTRODUCTION

Over the last two decades, a great amount of research has focussed on the alternative conceptions which students hold in relation to scientific concepts. In many cases, these ideas are quite different from the accepted scientific viewpoints and appear to be quite widespread. However, as Driver (1989) stated in her review of this subject : "One open question is the extent to which children's conceptions are genuinely 'theory-like', that is...being used consistently in different contexts."

One of the alternative conceptions which has been investigated for consistency is the idea that a moving body always has a force acting on it in the direction of the motion. Halloun and Hestenes (1985) found that about 40% of university physics students used this idea consistently when applied to linear and projectile motion. Finegold and Gorski (1991) tested university and high school students with questions concerning periodic, linear and projectile motion and found that "the motion implies a net force framework is not consistently applied". An important contribution has recently been made by Galili and Bar (1992) who designed a graded set of questions covering linear, periodic, circular and constant motion. They sampled high school and university students and found that pupils were more likely to use the "motion-implies-force" conception as the questions became less familiar. Thus, the data appear to indicate that this alternative conception is usually not consistently applied to different types of motion. We might predict that consistency would be higher if all the questions covered one, simple type of motion only. However, this still needs to be investigated.

Studies of consistency in other alternative conceptions in science have presented conflicting evidence. Vosniadou and Brewer (1989) studied conceptions of the Earth's shape, identifying "consistent concepts for the great majority of the children". However, Summers and Kruger (1992) found inconsistencies in their subjects' descriptions of energy, and Engel Clough and Driver (1986) reported that "students were using different alternative frameworks in response to parallel questions" on pressure, heat and inheritance.
The latter authors noted the importance of the context (or setting) of the question in determining an individual's response. Some authors have successfully identified critical

contexts which influence students' conceptions. For example, Whitelock (1991) and Fischbein, Stavy and Ma-Naim (1989) studied students' conceptions of motion and found that the type of moving body was an important factor for some.

The aims of this study were to investigate the degree of consistency of students' responses to questions solely concerned with linear motion, and to investigate the effect of context on consistency.

METHOD

The instrument

This study used a survey approach designed to identify broad trends in students' responses. The instrument consisted of a test entitled "Forces in Sport" containing 10 multiple choice questions which were selected after a pilot survey involving 72 university students. Two of the ten were distractor questions, not related to the investigation. The eight test questions (all of which are presented in the Appendix) concerned the direction of the force on a freely moving object in linear motion. They were written in simple language and described daily-life situations, and each was accompanied by a simple, line drawing to illustrate the problem. Each question had a scientifically correct response, one distractor which indicated that "motion-implies-force" (as used by Osborne & Gilbert, 1980, and Halloun & Hestenes, 1985), and two other plausible distractors.

To allow analysis of possible contextual effects the questions were systematically interrelated along three parameters: the nature of the moving object, the direction of the motion and the rate of the motion. For example, Question 1 concerned a ball being thrown gently in a vertical direction. In half the questions the moving object was a ball and in the other half the moving object was a person; in half the questions the direction of motion was vertical and in the other half it was horizontal; and in half the questions the implied rate of motion was "gentle" while in the other half it was "quick".

As suggested by Tamir (1990), subjects were asked to choose the best answer, rather than the correct answer. This had the advantage of requiring the students to analyse the relative importance of the options, if they believed that more than one was correct.

The test was validated by three physics lecturers at the University of Newcastle. Its reliability, based on the group described below, was shown to be acceptable (Cronbach's alpha = 0.81). Each of the questions had an acceptable facility index (ranging from .39 to .61), discrimination index (ranging from .19 to .26) and distractor efficiency (ranging from .01 to .16).

Sampling Procedure

The test was administered to all the Year 10 students (15-16 year olds) who were present in four schools in Canberra: a total of 567 students. One school was co-educational, one was girls-only and two were boys-only schools. One of the boys' schools was streamed and the other was unstreamed. All the students had studied forces at high school although some more recently than others. The students were asked to answer every question on the test. Those who did not answer every question (N = 22) were not included in the analysis. This was because the analysis of consistency required the assumption that eight questions had been answered.

RESULTS AND DISCUSSION

The test items and the percentages choosing each option are presented in the Appendix. In each question, both the correct answer and the "motion-implies-force" distractor attracted more responses than the other two distractors.

Consistency of Responses

The subjects were grouped according to how frequently they chose the "motion-implies-force" distractor (see Table 1). Of the 545 students, 19% never chose this distractor, with the remaining 81% choosing it at least once; for the whole sample, the average number of times this distractor was chosen for the eight questions was 3.1. Only 6% (N=34) of the students were totally consistent, choosing this distractor for all eight questions. This last figure is lower than was expected. Halloun and Hestenes (1985), found that 40% of their students were completely consistent. However, they tested university physics students and it is possible that this explains the difference. Licht and Thijs (1990), investigating another alternative conception, found that pupils in higher grades were more consistent than those in lower grades. The results for the correct responses show a similar pattern. Only 10% of the students were consistently correct, and the average number of correct responses was 3.9.

TABLE 1

PERCENTAGES OF SAMPLE SELECTING "MOTION-IMPLIES-FORCE" DISTRACTOR AND CORRECT ANSWER

Number of times this option was chosen

OPTION	0	1	2	3	4	5	6	7	8
motion-implies-force distractor	19 %	16 %	11 %	14 %	14 %	9 %	5 %	7 %	6 %
correct answer	13 %	10 %	9 %	14 %	14 %	10 %	8 %	13 %	10 %

This similarity appears to indicate that the inability of the majority of the students to achieve complete consistency is not just a feature of the alternative conception, but rather it may be rooted in a general inability to apply ideas consistently across different contexts, even when these contexts are closely related, as was the case here. In contrast, McCloskey (1983) studied alternative conceptions concerning motion and stated that "they are not random, but systematic. They arise from a general, coherent theory of motion that adequately guides action in many circumstances". The results from the present study indicate that this is possibly only true for a small minority of the students.

Effect of Context

Table 1 shows that many of the students chose the alternative conception either once or twice. Very little can be said about these two groups because probability suggests that in a test of eight multiple choice questions a person who was using random guessing would be expected to answer about two questions consistently.

However, a large number of people did choose the alternative conception either three, four or five times. It is possible that these people were responding fairly consistently to one of the contextual parameters (e.g. "ball" questions) but not the other (e.g. "person" questions). To investigate this possibility the data were examined in the following way.

Individuals who appeared to be consistent in one group of questions but not in the other were identified. The criterion was that the difference between their scores for each group should be at least 3. For example, one student chose the motion-implies-force distractor four times in questions which concerned a ball in motion, but chose the correct response in each of the four questions which concerned a person in motion; and another student chose this distractor in four of the "person" questions but in only one of the "ball" questions.

These results are presented in Table 2, which reveals that some people tended to answer "ball" questions differently from "person" questions (with more people applying the alternative conception to the former). Other people tended to answer questions about vertically-moving objects differently from horizontally-moving objects (with more people applying the alternative conception to the latter). Another group of people tended to answer questions about gently-moving objects differently from quickly-moving objects (with equal numbers in both).

TABLE 2
NUMBERS OF PEOPLE WHO CHOSE THE "MOTION-IMPLIES-FORCE" DISTRACTOR CONSISTENTLY FOR ONE GROUP OF QUESTIONS ONLY.

Context	ball	person	vertical	horiz.	gentle	quick
Total	20	3	11	36	5	5

Thus, it appears that some people believed that the type of object was important when considering the causes of the motion. Other studies have obtained similar results. Whitelock (1991) found that the animate nature of moving objects was an important factor to some students; and Fischbein et al. (1989) identified naive subjects whose responses were influenced by the shape, the weight and the function of the moving body.

The results also indicated that the direction of movement may have been an important contextual factor for some people. A relatively large number of people in this group chose the alternative conception when the object was moving horizontally rather than vertically. It is possible that these people were selecting gravity as being the main force operating in vertical movement but that in horizontal movement the main force was the "force in the direction of the motion". The individual results show some support for this: several students chose the correct response in the four "vertical" questions, but chose the "motion-implies-force" distractor in the four "horizontal" questions.

However, these people whose patterns of responses separated the questions along broad contextual lines represented only a small percentage (15%) of the total group. It is possible that other people were perceiving more subtle differences between contexts. To investigate this, the data were examined in the following way.

The questions were paired according to contexts which they had in common. For example, there were two questions about a ball moving vertically, two about a ball moving horizontally, and two about a person moving vertically. For each pair, the number of people who chose the "motion-implies-force" distractor in both questions was found. The results are shown in Table 3.

TABLE 3
NUMBERS OF PEOPLE WHO CHOSE THE "MOTION-IMPLIES-FORCE" DISTRACTOR IN BOTH OF TWO CLOSELY-RELATED QUESTIONS

Context	Total	Context	Total
ball horiz.	164	person gentle	89
ball vertical	182	person quick	118
person vertical	111	vertical gentle	95
person horiz.	113	vertical quick	132
ball gentle	131	horiz. gentle	145
ball quick	134	horiz. quick	135

It is apparent that some combinations of questions attracted considerably more responses than others. The questions concerning a ball moving horizontally attracted the greatest number, followed by the questions concerning a ball moving vertically. Thus, there is some evidence that people were responding to an interplay between contexts. For example, one student chose the correct answer in five of the questions, had one incorrect, but chose the "motion-implies-force" distractor in the two questions concerning a ball moving horizontally.

IMPLICATIONS FOR RESEARCH AND TEACHING

Although many students applied the "motion-implies-force" conception in some contexts, very few consistently generalised it to a range of everyday situations. The fact that this also applied to the correct scientific theory points to a general problem which students seem to have in recognising the similarities between contexts. Teaching procedures need to be developed which enhance this skill.

For some people, it is possible to identify certain contexts in which the "motion-implies-force" conception is more likely to be used. These include motion in a horizontal direction, motion of a ball rather than a person, and particularly a combination of these: motion of a ball in a horizontal direction. This information has a potential use in the process of conceptual change. Put very simply, this process requires individuals to recognise that they have an understanding which is not satisfactory, and then to change it by exposure to a range of situations; see Driver (1989) and Saunders (1992). Thus, it is important for the teacher to select contexts which as many students as possible will relate to the alternative conception. The ones identified above could hold promise for this.

The findings of this study need to be corroborated by further research of a more qualitative nature involving techniques such as diagnostic interview. The broad trends identified above should provide fruitful areas for further research in this field.

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APPENDIX

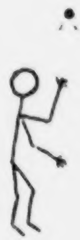
The test questions are presented below. The numbers in brackets are the percentage who chose each distractor (N=545).

FORCES IN SPORT

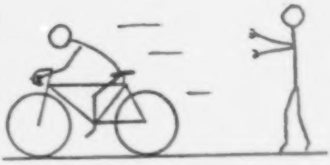
Please circle the best answer from the ones given.

1. A person gently throws a ball straight up into the air. When the ball is on the way up (and well clear of the person's hand) the total force on the ball is

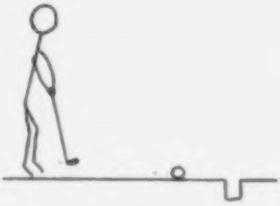
   A. up (35%)
   B. zero (10%)
   C. down (39%)
   D. none of the above (16%)



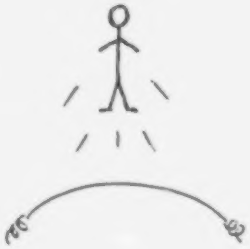
2. At cycle training at an indoor stadium, a person gives a cyclist a push start along a flat, level stretch of the floor to see how far the bike will roll before it stops. The cyclist does not pedal. While the bike is rolling straight forward at some speed (after it has been pushed), the main force affecting the cyclist would be in which of these directions?
- A. ——> (56%)
- B. <—— (34%)
- C. side on to the cyclist (2%)
- D. no force (8%)



3. A golfer gently hits a golf ball so that it rolls across the flat, level green and falls into the hole. After the ball has been hit, and while it is still rolling slowly forward towards the hole, the motion of the ball would be mainly influenced by
- A. a force attracting it to the hole (2%)
- B. a force acting on the ball in the direction in which it is moving (50%)
- C. no forces at all (8%)
- D. a force acting in the opposite direction to which it is moving (41%)



4. A gymnast is jumping on a trampoline. On one jump, after the person has left the trampoline and is going upwards rapidly, most of the force on the person would be in which direction?
- A. in a downwards direction (55%)
- B. in an upwards direction (39%)
- C. in no direction because there would be no force on the person (4%)
- D. in the direction in which the person is facing (1%)

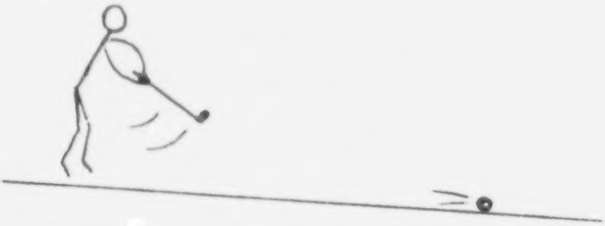


5. A girl on roller skates gently pushes off from a wall and slowly rolls a short distance along a flat, level path. She does not attempt to skate forward, but just rolls until she stops. As she is rolling slowly forward (well away from the wall) she would be mainly influenced by a force
- A. from the wall, repelling her (16%)
- B. pushing her to one side or another (2%)
- C. acting in the direction she is moving (36%)
- D. acting in the opposite direction to which she is moving (46%)

6. In cricket, a batsman misjudges a shot and hits the ball so that it goes straight up high into the air. After the ball was hit and while it was travelling rapidly upwards the main force on the ball would have been
- A. acting downwards on the ball (52%)
- B. no force present at all (3%)
- C. acting straight upwards on the ball (35%)
- D. none of the above (9%)

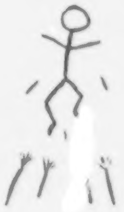
7. A hockey player hits a ball which rolls very quickly along the flat, level surface of the hockey field. As the ball is moving quickly along (well after it has been hit) it would be mainly affected by a force in a

A. sideways direction (2%)
B. backwards direction (42%)
C. forwards direction (49%)
D. no force present (7%)



8. After winning the grand final, the team lifts the coach up and throws him gently up into the air 3 times to celebrate. On one of these times, after the coach has been thrown and while he is still moving straight upwards, the main force on him would be

A. acting straight upwards (28%)
B. acting straight downwards (61%)
C. absent, or no force (4%)
D. none of the above (7%)



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THE ROLE OF CLASSROOM RESEARCH PROJECTS IN THE PREPARATION OF SCIENCE TEACHERS

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ABSTRACT

Research undertaken by educational researchers based in universities has not had the desired impact on the practices of classroom science teachers. Yet Goodlad (1990) has argued that if teaching is to be recognised as a profession there is a great need for the marrying of the knowledge of the practitioner with that of the researcher. Student teachers might learn to respect the potential for such a union by undertaking minor classroom research projects during their teacher preparation programs. This paper discusses the role of research projects in pre-service teacher preparation with reference to an inquiry conducted with teacher education students.

INTRODUCTION

Research undertaken by university-based teacher educators has not been readily accepted or implemented by classroom science teachers (Goodlad, 1990; Tobin, 1990; Tobin, Kahle & Fraser, 1990; Tobin & Fraser, 1987, 1990). Researchers have attempted to promote such diverse issues as constructivism (e.g. Tobin, 1990) and gender equity (Beasley, Butler & Satterthwait, 1992; Tobin, Kahle & Fraser, 1990), but these developments have had only a limited impact on classroom practice. Tobin (1990) attributed the limited impact of recent developments in science education to the failure of researchers and other reformists to address the process of teachers' re-conceptualisation of beliefs and practices. A few recent case studies, where university researchers have worked collaboratively with teachers in their own classrooms, have met with some success (Baird, Fensham, Gunstone & White, 1991; Briscoe, 1991; Ritchie & Russell, 1991; Tippins, Tobin & Hook, 1992; Tobin, Briscoe & Holman, 1990). In these cases the teachers took on an active and intentionally systematic inquiry of their own practice; the teachers were able to reflect on their practices and explore their beliefs and assumptions about teaching and learning. In other words, the teacher assumed the role of "teacher researcher" (Erickson, 1986; Goodlad, 1990; Lytle & Cochran-Smith, 1992). Lytle & Cochran-Smith (1992, p. 458), for example, described teacher research in the following terms:

> Teacher research is a powerful way for teachers to understand how they and their students construct and reconstruct the curriculum. By conducting inquiry on their own practices, teachers identify discrepancies between their theories of practice and their practices, between their own practices and those in their own schools, and between their ongoing assumptions about what is going on in their classrooms and their more distanced and retrospective interpretations. Inquiry stimulates, intensifies, and illuminates changes in practice. Out of inquiry come analytic frameworks, as well as questions for further inquiry.

This paper explores the development of the teacher researcher role in pre-service teacher education programs through classroom research projects.

Zeichner (1992) noted that many teacher education programs which advocate reflective teaching provide only an illusion of genuine teacher development. He argued that an emphasis on either "external" theory or "internal" practice rather than a "dialogical relationship" between theory and practice, "denies the teacher the use of the wisdom and expertise embedded in her own practices and in the practices of her colleagues" (p. 6). Similarly, Goodlad (1990, p. 19) argued that in order for teacher reform to begin: "teaching, a profession of teaching, and teacher education must derive their mission and their substance from the richly layered context within which teaching decisions are made". Innovative approaches such as "Cases" (Richert, 1991) and "Action Research" (Noffke & Brennan, 1991) have been used by teacher educators to help student teachers "to realise the dialectic of action and reflection in their daily experiences of reflective practice" (Noffke & Brennan, 1991, p. 193). While numerous claims about the effects of such research projects exist (see Richert, 1991), there is an overall lack of documentation of research projects with pre-service teachers which inhibits judgements as to their usefulness (Noffke & Brennan, 1991). Therefore, the learning opportunities from research projects undertaken by my final year primary science education students become the focus of this exploration.

LEARNING FROM RESEARCH PROJECTS

Although I have assigned a variety of research projects for my students, my discussion draws on data from a self-directed inquiry into the learning associated with ethnographic projects (see Barnes, 1992). The data sources included: my students' reports, their reflections, transcripts from interviews I conducted with a sample of my students six months after graduation, comments from a school representative, and my own personal reflections.

Description of Research Task

I decided to experiment with classroom inquiry for two reasons. First, I had been searching for and trialing various methods which provided constructivist learning experiences for pre-service teacher education students since my successful encounter with constructivism in my post graduate class (Ritchie & Russell, 1991). Second, I had received an invitation by staff from a local high school to help them identify the perceptions of students about the Year 8 science curriculum. The question: "What is it really like to be a Year 8 science student?" not only beckoned the use of ethnographic techniques, but also provided an opportunity to explore the potential of using such a task as a focus for learning about science classrooms in the constructivist mode for my students.

While the majority of students opted to undertake an alternative project, six students volunteered to complete the ethnographic task. Because the students had no previous experience or training in research, we worked through a number of issues together as a subset of the class. These meetings usually occurred after hours and sometimes in lieu of normal class time when all students were given the opportunity to prepare work for their projects.

After the first meeting between the student researchers and school staff, we decided to conduct three separate ethnographies, each focussing on a separate class. This provided a reasonable spread of classroom environments and a realistic goal in the limited time available. For convenience and support the student researchers teamed-up in three pairs; the allocation of classes to pairs was negotiated by the student researchers.

During the next four to six weeks each team negotiated classroom visits and student interviews directly with their respective teachers. The following extract illustrates the typical procedure followed by the teams:

> We began by making general observations of the classroom to familiarise ourselves with the focus class. Informants were then selected with the teacher's assistance. The description which we will develop of 8F emerged from the information given from the perspectives of six students (5 females, 1 male) over a number of visits during regular science lessons. We withdrew the informants individually for this purpose. Our last visits were conducted with just three informants, who tended to be more eager to provide information in detail ... [Stan & Catherine, p. 1].

As well as visiting the schools twice a week, the student researchers met together with me each week to discuss issues related to ethics, organisational difficulties, emerging themes and questions, and writing style. During these meetings we shared our understandings and attempted to make sense of the data.

Even though we attempted to engage in the process of ethnography as described by Spradley and McCurdy (1972), it was not possible to satisfy the criteria for good ethnography (see Spindler, 1982); nor would it have been possible for experienced researchers to satisfy these criteria in such a short period of time. Nevertheless, we set out to conduct three classroom ethnographies, albeit naively, using the ethnographic techniques of interview and observation. While the process and product of our work fell short of good ethnography it did not diminish the learning outcomes for each of the participants (c.f. Barnes, 1992).

Learning Outcomes

When the range of student perspectives was revealed in our meetings, the student teachers began to realise the complexities of classrooms and developed a better appreciation of some of the problems encountered by classroom researchers. This point was supported by the following extracts from the student researchers' post-course reflections:

> This first attempt at an ethnography was initially a very daunting task! I found it difficult to write true accounts and resist the temptation of being too judgemental or leading in questioning [Rachel].
>
> Writing the transcripts earlier would have helped narrow the focus. I can also see the value in using fewer informants. However, I needed to find this out for myself [Catherine].
>
> We found it hard to develop a trusting, open relationship with our informants in such a short amount of time. To produce a more accurate report we feel more time was needed to develop rapport with these children. It would be interesting to compare a similar ethnography from the beginning of the year [Lorna & Cameron].

Rather than developing a new-found respect for the research enterprise, the ethnographic experience led my students to realise the potential significance of the "teacher as researcher" role (see Erickson, 1986). The following extract is representative of the supporting comments received during interviews I conducted with three of the student researchers, six months after the course:

> Essentially, as a teacher you are a researcher all the time. You are always finding out information, putting it together, coming up with ideas. ... So you know as a teacher you are a researcher anyway and an ethnography is a good way of making you feel even more like a researcher, I think. I believe one of my roles as a teacher is a researcher [Katie, June, 1993].

The direct comments made by Catherine and Katie, as well as indirect references to the researcher role made by Rachel in her interview, show promise for teaching as a profession. Erickson (1986), Goodlad (1990), Lytle and Cochran-Smith (1992), and Noffke and Brennan (1991) have all argued the need for teachers to take on the responsibility for research in their own classrooms. If an experience in a research project can sensitise student teachers to the need for a research role in the classroom, wider use of this approach might lead to the teaching profession's "coming of age" (Erickson, 1986; Goodlad, 1990).

While the research experience helped the student researchers to gain a better appreciation of the relationship between research and teaching, it appeared to affect their attitudes to research differently. Catherine claimed that she was no longer "fearful of research", Katie became more interested in research as a possible career, and Rachel has become more cautious and discerning of the products of previously unchallenged research reports - all three dispositions to be applauded. The following extract reveals Rachel's thinking towards research:

> I: What about the research literature?
>
> R: I tend to be more critical of it now. Because having written our ethnography it is very easy to make up things as you go along if you want to. You have to be so careful not to take things out of context, not to change wording, not to find information you want to find. I'm definitely more critical of the things I read.
>
> I: In what ways are you more critical?
>
> R: Well, when someone gives you a whole lot of facts and figures and statistics and things like that you sit back and think: "OK, Where did they get that from? Who's their control group?" It's just like us trying to generalise about the whole of Year 8 Science from the one ethnography - you just can't do it. So I just think that, especially at uni, you get taught that if it is written on paper it's it, it's biblical. I think that when you do something yourself, like that, you know that it's not... I know that we worked very hard to make sure we didn't take anything out of context but the argument is it can be done if you want to do it. I'm just really cautious of things like that now.
>
> I: So are you more cautious of what you read?
>
> R: Yeah, and I won't just read the research without asking questions about it. Without questioning what they have written, where they have got it from. I had never questioned things like that before. Those kids really had an impact on me ...[Interview Transcript, May, 1993].

While the "kids" made an impact on Rachel, one might ask "What impact did the student researchers have on the school?" and, on a more personal level, "What did I learn?". When the completed ethnographic reports were returned to the school, the initial reaction was one of surprise. Like the student researchers and myself, the teachers did not expect that the social dynamics of classroom life would feature so prominently. In particular, we were all surprised that peer acceptance was such an important issue for kids that some of them would sacrifice their own aspirations and possible achievements in order to gain peer approval and acceptance. Commenting later on the impact of the report, one teacher claimed that:

> The information turned out to be very useful. It helped us to find where the kids were coming from. It put your feet back on the ground. As teachers, our influence isn't as much as we would like to think [Interview transcript with Head of Department, June, 1993].

As a science teacher educator, "my feet" too were brought "back on the ground". I have begun to question the need for "teaching" as wide a set of topics and issues as I have done in the past, especially where an over-emphasis on philosophical argument and university-based research trends detracts from meaningful explorations of the psychosocial classroom environment. For example, is it better for student teachers to grapple with the philosophical idiosyncrasies of various approaches to science teaching or to develop the inclination and sensitivity towards promoting active learning? I now know that my students can learn a lot about constructivism by working in such an environment at university; the ethnographic process became a referent for discussion, clarification and social construction of ideas for teaching and learning. As Katie revealed:

> ... I found that from the ethnography children have to be motivated even if the kids are off-task a bit. This is what the kids in the science class put forward. That things need to be more interesting, more fun. The ethnography really made me think, "I will never teach like that!" [Interview transcript, June, 1993].

DISCUSSION

A course which is built on student research projects is radically constructive (von Glasersfeld, 1989) in that the students have the opportunity to discover their own questions, formulate their own understanding, and draw on their own experiences to make sense of their data (Barnes, 1992). This means that the teacher educator must discharge some responsibility for setting the learning agenda; this task is now shared by all participants: teacher educator, student teachers and their informants. It is inclusive of students' voices and grounds the curriculum in the students' experience. In this way, student teachers have the potential to experience emancipatory knowledge construction. O'Loughlin (1992) described emancipatory constructivism as:

> a reaction against the positivist doctrine that objective truth exists and that by using certain rational modes of thinking we can arrive at authoritative knowledge that can then be imparted to others. ... Emancipatory knowledge ... "increases awareness of the contradictions hidden or distorted by everyday understandings, and, in doing so, it directs attention to the possibilities for social transformation inherent in the present configuration of social processes". In education this critical and emancipatory notion of knowledge construction underlies critical and feminist pedagogies ... and critical studies of the social construction of pedagogy (pp. 336-337).

O'Loughlin (1992) notes that while constructivist approaches to teacher education are becoming more popular, very few are emancipatory. Student teachers' classroom-based research projects can be emancipatory if they help them to view their pre-service education as only a preparation "to begin teaching" (Zeichner, 1992, p. 4).

The outcomes from my inquiry support the claims by other researchers that research projects undertaken by student teachers enhances reflective thinking (Richert, 1991) and helps develop favourable dispositions towards teacher research (Klapper & White, 1993). More importantly, however, one would hope that these teachers would sustain such thinking and behaviour throughout their careers. By taking control of their own ongoing professional development teachers might become more sensitive to their students' needs. As Rachel suggested: "... let kids have a say to find out what are the problems and issues" [Interview transcript, May, 1993]. Only when all of us involved in education give each other voice will it be possible to engage in what Goodlad (1990) called the "moral enterprise" needed to initiate and sustain the reform process.

The implications of this work for teacher educators is clear. If we value educational reform, we must adopt teaching methods which foster a dialogical relationship between theory and practice. By our own actions we will demonstrate to our students that we value their voice and are prepared to negotiate rather than assign the curriculum. Working with our students in such a collaborative manner might indeed establish a career-long quest for understanding of one's beliefs and practices.

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FACILITATING PRACTITIONER RESEARCH INTO STRATEGIES FOR IMPROVING COMMUNICATION IN CLASSROOM GROUPS: ACTION RESEARCH AND INTERACTION ANALYSIS – A RECONCILIATION?

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ABSTRACT

This study involved collaborative classroom-based observation of student communication and cognition in small groups after the implementation of two management strategies in science departments in several schools. The paper presents the data and provides insights into the conduct of research and teacher development in the midst of educational change.

COOPERATIVE GROUP WORK IN SCIENCE CLASSES

The Australian Science Education Project (1970) argued that cognitive development would most likely be achieved in the social setting of the small classroom group. Little advice was however offered to teachers on the functioning of groups although some staff recognized the lacuna in the education of teachers. Subsequent research into classroom practice showed Bennett and Dunne (1990) that what generally passed for groupwork was in fact pupils sitting closely together but often engaged on individual tasks. In such groups they found that the level of cooperation, frequency of explanation and knowledge exchange was low. In order to acquire an understanding of cooperative learning in groups, collaborative research was initiated with teachers in a number of schools. In classrooms in which cooperative groups were set up normal curriculum materials and tasks were used with the specific aim of seeking relationships between teachers' management stategies, group processes and pupil understanding (Sadler & Fawns, 1992). We sought to investigate the claims made for cognition in cooperative group work by Sharan (1990), Johnson and Johnson (1984), Slavin (1990), Ross and Raphael (1990), but also to provide some insight into classroom implementation and the critical role of the teacher.

THE FACILITATING RESEARCH DESIGN

We had three main objectives in developing this particular research design:

- to compare high and low structure management strategies for promoting communication and learning in small groups in science classrooms;
- to study student communication and behaviour whilst the students were engaged in small groups; and
- to involve teachers in investigations of their own teaching and to engage their interest in student communication and learning in groups.

We never proposed to the teachers we approached that the quantitative analysis of student communication in cooperating groups in their classrooms would be sufficient to lead to an improvement of teaching. Our purpose was to focus teacher attention upon their role in the management of effective group learning. In making the suggestion that the research proceed as shown in Fig. 1, within a simultaneous integrated action research model (Kelly, 1985), we explained that we may be able to gain further insight from comparisons across year 8 classes in four schools.

		CONTENT A (Phase 1)		CONTENT B (Phase 2)	
Class 1	Pretest survival problem	Strategy 1 4 Weeks	Survival problem test	Strategy 2 4 weeks	Survival problem test
Class 2	Pretest survival problem	Strategy 2 4 Weeks	Survival problem test	Strategy 1 4 weeks	Survival problem test
Class 3	Pretest survival problem	Strategy 1 4 Weeks	Survival problem test	Control 4 weeks	Survival problem test

Fig. 1 Research Framework - Schedule of three year 8 classes within each school.

Strategy 1 was an adaptation of an instructional treatment developed by Yager, Johnson and Johnson (1985). One student took the role of reporter and was required "to restate the main points of the lesson, the remainder of the group was required to ask probing questions, recall omitted content and discuss facts and ideas incorrectly presented." This strategy we described as the low role strategy (LRS). It was anticipated that this procedure would address the cognitive demands of the task and stimulate discussion of the facts and concepts to be learned; communications which correlate positively with achievement.

Strategy 2 was an adaptation of the Student Teams Achievement Divisions (STAD) developed by Slavin (1990) and used by Ross and Raphael (1990). Each student was assigned a role defined as "reporter", "recorder", "manager" or "technician" and the emphasis of group work was on the successful completion of appropriate tasks. This strategy we described as the high role strategy (HRS). It was anticipated that by addressing managerial demands the communications would tend to be negatively associated with achievement. Students wore badges to remind themselves and their teacher of their roles and tasks within the group.

The third parallel class was used as a control with which to compare the two experimental management strategies. No specific roles were assigned to group members in this class (NRS). The teacher called on any student to report on their own or their group's work in a fashion regarded as a more typical laboratory management strategy. Classes were randomly allocated to treatments.

Teachers selected their own teaching material, content A and content B as shown in Fig. 1, but were encouraged to use ASEP style units or similar investigative approaches which allowed for small group investigation in each lesson. Each of two topics was studied simultaneously by the three year eight classes for a period of about four weeks. The total treatment period was a minimum of eight weeks in each school. The test of achievement was a problem solving task (Fig. 2), adapted from Gott and Murphy (1987). It invites the groups to design an experiment on the heat insulating properties of two materials, a task that was unrelated to contents A and B.

Outcome measures reported here were derived from the assessment of written practical reports and also coded group conversations during the problem solving task. The coding system for the latter was that used by Ross and Raphael (1990), originally developed by Cooper (1982), and tested and adapted for this study. Student statements were identified within the written transcript and student talk was coded into categories at three levels.

THE SURVIVAL PROBLEM

Imagine you are stranded on a mountain side in cold and windy weather. You can choose a jacket made from one of the fabrics in front of you.
This is what you have to find out:

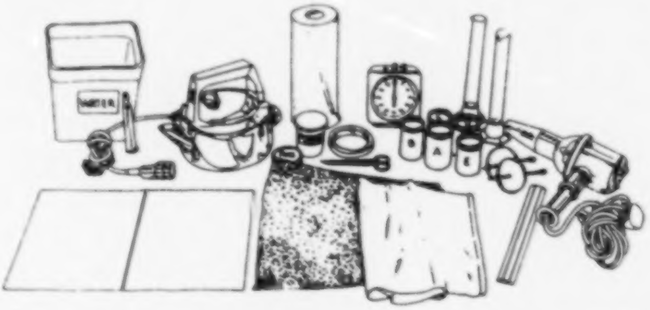
Which fabric would keep you warmer?

You can use any of the things in front of you. Choose whatever you need to answer the question.

You can use:

- a can instead of a person
- make a 'jacket' from the material
- put water inside to make it more life-like
- use a hairdryer to make an imitation wind

Make a clear record of your results so that other people can understand exactly why you have decided which material would best.



Describe the experiment you could do to find out what material would be best.

- the things you would use
- how you would measure them
- how you would work out your results
- the things you would measure
- what you would do to make it a fair test

Fig. 2 The Survival Problem

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ANALYSIS OF THE CODED COMMUNICATIONS IN TWO SCHOOLS

Four schools were involved in the final study, a total of twelve classes and eight teachers. We are reporting illustrative results from two schools. The coding procedures allowed us to collapse the communications coded on function into three categories in the same manner as used by Kempa and Ayob (1991). We are commenting here only on the amount of communication at a high level of cognition which we described as conceptualisation. The other types of communication had procedural and descriptive functions. The data collected for the three classes in schools A and B are shown in Tables 1 and 2 respectively.

In school A the data collected during the problem solving task suggested that the use of a managed strategy (the LRS and HRS taken together) as compared with the control treatment resulted in a statistically significant improvement ($p < .05$; t test of group means) (Mendenhall et al., 1989) in conceptualisations as shown in the right hand column. When teachers used the low role structure, strategy 1, as compared with the control treatment, the statistical tests indicated a significant effect ($p < .05$; t test of group means) in increased conceptualisations. The statistical test did not support a significant result for the high role structure, strategy 2 when compared with the control treatment.

TABLE 1
MEANS AND STANDARD DEVIATIONS OF THE RELATIVE FREQUENCIES OF CODED COMMUNICATIONS IN ROLE STRUCTURED AND UNSTRUCTURED GROUPS (SCHOOL A)

		PROCEDURES Mean % (s.d.)	DESCRIPTIONS Mean % (s.d.)	CONCEPTUAL ISATIONS Mean % (s.d.)
NRS	8A Pretest	71	23	6
	8B Pretest	49	43	8
	8C Pretest	56	37	7
	8C Phase 1	61	36	3
	Mean	59 (9)	35 (8)	6 (2)
LRS Strategy 1	8A Phase 1	46	46	8
	8B Phase 2	53	34	13
	Mean	50 (5)	40 (9)	10 (4)
HRS Strategy 2	8B Phase 1	64	29	7
	8C Phase 2	26	60	14
	Mean	45 (27)	45 (22)	10 (5)

In school B, the results were different in some important respects. The data collected during the problem solving task suggested that although not statistically significant the HRS structure produced increased communication in conceptualisations in the group but the LRS structure was significantly inferior to the control.

We concluded that school environmental effects were important in cooperative learning, a view which the teachers found to be unsurprising. School B was a technical school in which group work was rarely used, didactic teaching predominating. Teachers and students predicted that the low role strategy would be unlikely to succeed in their school, a view supported later by the data analysis.

TABLE 2
MEANS AND STANDARD DEVIATIONS OF THE RELATIVE FREQUENCIES OF CODED COMMUNICATIONS IN STRUCTURED AND UNSTRUCTURED GROUPS (SCHOOL B)

		PROCEDURES Mean % (s.d.)	DESCRIPTIONS Mean % (s.d.)	CONCEPTUAL ISATIONS Mean % (s.d.)
NRS	8A Pretest	58	27	19
	8B Pretest	43	47	9
	8C	66	28	6
	8C Phase 1	57	37	6
	Mean	52 (12)	40 (14)	8 (4)
LRS Strategy 1	8B Phase 1	55	43	2
	8C Phase 2	45	52	3
	Mean	50 (7)	47 (6)	2 (1)
HRS Strategy 2	8C Phase 1	46	42	11
	8B Phase 2	60	32	8
	Mean	53 (10)	38 (7)	10 (3)

The result in school B can be contrasted with Ross and Raphael's (1990) finding in favour of the LRS. The result in school A, a more typical high school, tended to support Ross and Raphael's results. In school A the group achievement on the written practical report showed improvement over time with the use of either managed strategy as compared with the control treatment. Statistical tests on these reports did not support significant improvement in 'setting up' the investigation but did support a significant improvement over the control ($p < .05$; t test of group means) in 'making measurements'. In school B there was negligible change in the written practical report over time in any group.

The pooled data from the four schools showed there was a significant relationship ($p < .05$; t test of means) between the implementation of cooperative group work and a higher level of cognition in these groups, compared with a control.

MANAGING SIMULTANEOUS INTEGRATED ACTION RESEARCH

We were anxious about the teachers' response to the formal research procedures in terms of their understanding and practice. Prior to the research, teachers thought that their involvement would be good for staff morale in that it would bring the faculty together by focussing on the problem of managing student learning in small groups. Teachers volunteered that their practice was problematic in the area of cooperative learning and that they were looking for support to try new approaches.

After the data had been gathered, structured group interviews were conducted in each school. The teachers were asked to explain why they became involved in the research.

B Well I don't know, I reached a stage in my career where I thought I was looking for new ways in which I could handle kids. I thought there were a lot of avenues I'd exhausted and I was just keen for people to come up with ways of management.

S I'm always interested in some new methods of teaching. It not only assists your work but it revitalises your approach and makes you think about your own teaching methods if nothing else, so that's why I thought it was a good idea.

Q Did the questions seem appropriate to your school at the time?

S Yes they did. Actually the first question was whole-class work versus group work. That was the one that I was really interested in. I think group work answers quite a few of the problems we're having and structured or unstructured groups was a technical thing I hadn't thought about so therefore it was interesting. The first question really was group work, I wanted to revise my knowledge and see how I could utilise it for different things.

Sc I was interested in what it would be like as I was having some management difficulties with regard to group work. It took a while to learn to manage the groups in the best way.

The teachers may have regarded generalizability as irrelevant (Cummings, 1985), not of prime importance or implausible. After all, as Cronbach (1975) observed, when we give proper weight to local conditions any generalization is a working hypothesis, not a conclusion. Quite lengthy discussions occurred both before and during the eight week experimental period about the design and the generalizability of the results.

Q Had you thought about the possible outcome of the investigation prior to the activity?

P That every group would have its own work bench area and have specific roles. I really thought the structured group would be better. I'm using it now, a certain workbench area, same partners and each person has a certain task for that lesson, which is decided at the start of the lesson.

S Yes, you assumed that group work goes on. You were interested in the nature of the group work rather than group work versus other methods so really for me there were two questions.

In action research Gibson (1986) says teachers work out their own solutions to their own (not others) problems and employ their own language and concepts rather than those of the "experts". Action research, McTaggart (1991) claims is "initiated, conducted and is disseminated from the inside." Did the teachers feel any ownership ?

Q Did you feel it was our research or did you feel in some respects that it was yours? From what you're saying you had your own questions going right through it ?

S Yes. I was sort of using you for the problem I had, I suppose, although I did think it was your research. At the same time I was addressing a problem that I had, but I hadn't thought of it as research — just a problem.

Sc The big question for me became the time used in practical work and group discussion. A single period for a lesson is hopeless for discussion and action with the larger groups of four. Chemical separation and electronics need doubles.

P Although I was "the control" I got involved in group management. With my control group I chose to work with pairs. I tried threes but had to go back to pairs. Four in a group was pretty bad. It was OK for complicated practicals when you could break things up but in a simple practical, students became bored and then there were problems.

Q Did the involvement in the research make you look at your own teaching?

P Yes, it benefited me in my teaching. Your strategies not only get them off their seats to do practical work but make them think about the group work.

Sc The research question with tests on student's problem solving at lunchtime was wider than just helping me with my problems.

Q If we'd taken an action research approach rather than the experimental research design would you have preferred that?

Sc With action research, it would be good but I don't know if you'd get any meaningful results. It would be good to have input into the research but there would be so many variations and you'd have to control it. I was happy to go along with the research question and once I knew what was going on I became committed to it and to using the different management styles for the group work.

P Using this experimental design where we felt we were stuck using a particular strategy that was not working and didn't want to continue – this caused worries. I personally think action research is good because you can change things as you go. The best outcome for me from this research is that I've pinched little bits and pieces and used them to suit my classes and teaching style.

Q Should we now action research some of these ideas in another school rather than continue with the style of research we've used here?

P The classic research style – as we did it – forced us into a position to do certain things. How else would we have found out what was good about the group work unless you'd set it up. Perhaps now we can work on the better things and perhaps change things around until we get things as we want them. The other thing with me is I don't really worry about other people. I go off and do my own thing. The other two teachers liked to have a set thing to do and were happy to explore their own teaching within those roles. I don't think the result matters. It's being involved which is important. I think a lot of people are similar. You have to have people to push and encourage you. We should be doing that with younger teachers.

The teachers in this study had no test data during the eight week period. Analysis occurred later. They did however discuss their impressions of how the two strategies were working in their groups with their colleagues and with us. These colleagial discussions no doubt influenced their actions. In several cases, as they explained above, these resulted in a changed experimental design and prevented certain key comparisons.

Q When you changed the experimental design, were you aware of the possible consequences to the results?

Sc Yes, I was aware I was messing up the research. But with the arrival of a student teacher, it wasn't working out and the Geology topic didn't lend itself to using group work as Metals had.

S Oh yes. We regrouped some troublesome groups. I didn't change things before I discussed it with you. There might be more than one way of addressing the problem so I wouldn't do that without asking you.

We felt quantitative data could challenge mythologies and reveal new problems. In particular we felt the research could provide useful generalizations which could help clarify both the extent and distribution of problems and the existence of cultural influences which transcend the individual teacher. In allowing direct comparison of alternative pedagogies we felt it could help teachers with their own policy decisions.

Q If we did more of this sort of research could we smuggle the idea of group work into the teachers' agenda?

P Yes, you did that to me. I've always done a lot of practical work but I've never thought about groups much before. The kids work with partners now for a whole topic and now you can get them interacting and talking. I now get two groups of two together to talk about their ideas. They might answer questions together about the practical work such as writing word equations. I try to mix up the girls and the boys. Each student writes their own answers. I don't like a single combined report as I think the group gets the best student to write it.

Q So you think, S, that the high structure would be the one that you would be inclined to use.

S Yes. It would be good to use with year 7. You see I haven't done Mice and Men that way before but again they're 2s. You see they're 2s within 4. The aim is to develop some cooperation so we'll try it with year 7.

Q Some people are worried about groups because they think the groups will have a life of their own and take over from the teacher.

S I'd be delighted if they did take more responsibility for their behaviour.

B Groups tend to control their membership, they have a life of their own alright but it tends not to be disruptive, rather to be internalised. So where there might be anti-social elements they might be directed to the teacher; if the teacher insists upon individualized mode of instruction. Whereas in a group, the group looks after some of that.

From these comments it is clear that there are limits to the impact of data derived from interaction analysis on the improvement of teaching. The authentic voice of the teacher expressing their own experiences and concerns entered the design in the framing of the two alternative strategies in the pilot studies and the language of research needs to present the work of teachers in their own terms when reporting on teachers' thinking. However it would seem severe to claim that there is a dichotomy in the dialogue between interaction analysis and teacher-researcher action research which impedes development and communication and that only the latter can inform and improve practice.

CONCLUSION

In relation to our initial objectives we found the research design permitted some important comparisons to be made within and between schools. The active strategies were generally more successful on all measures than the unstructured control strategy. Smaller differences were found between the two active strategies and those differences seemed to reflect school conditions.The teachers varied the experimental design as it proceeded, limiting some comparisons, but allowing investigation of key issues of basic concern to them in managing group work in their classes. An informal conclusion reached by students and staff was that a higher level of meaningful task-centred communication occurred in the managed groups than in the control. Prior success in group work seemed to be important as were also the gender composition (Stacey & Gooding, 1992) and the style of leadership in the groups (Gayford, 1992). These issues are worth further experimental investigation.

Teachers in all schools with whom we worked sustained commitment to the three objectives of the study. All staff interviewed were able to indicate ways in which they were using the findings. Subsequently schools A and B were involved in amalgamations resulting in staff and students moving between campuses. This highlighted difficulties with ongoing research partnerships for faculty development. In both schools however teachers were keen to discuss the results and involve us in further school based professional development. A major outcome of the research was the facilitation of teachers' interest in classroom enquiries into student classroom behaviour and management. In some respects they negotiated the research as their own, including the conduct of the problem testing procedures We wanted to be sure of getting results that we could use and the teachers were happy to organize the student groups to meet us for the testing sessions in predetermined lunch times every three weeks and keen to have us around in classes in between. We respected each others' professional needs and concerns.

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EMERGING ISSUES CONCERNING THE FUTURE DIRECTIONS OF AUSTRALIAN SENIOR SCIENCE EDUCATION: THE QUEENSLAND EXPERIENCE

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ABSTRACT

Australia's changing political, social and economic agendas have triggered a critical analysis of school curriculum. Part of this consideration has been concern over the future of science education within the context of senior schooling. Following the completion of the Senior Science Future Directions Project commissioned by the Queensland Board of Senior Secondary School Studies, fifteen issues were identified. These issues, grouped by the needs of the science disciplines, society and the individual student, are discussed with the view of understanding the future design of senior science syllabuses.

INTRODUCTION

Senior science education in Australia may be characterised as being in transition; a transition from a strongly discipline-based, university-driven curriculum to science subjects with more varied curricular approaches and a wider range of subject goals. This change has been initiated by the active involvement of new stakeholders in senior science education. Recent growth in post-compulsory school retention rates, increased demand for economic accountability within all government institutions and perceived needs of individual students are all forces driving this need for change in subject design.

In the past, science education within western societies became keenly focused on a knowledge base defined by discipline practitioners. During the 1950s a chronic shortage of scientists forced a dramatic change in school science to entice students to enter the science disciplines and to better prepare these neophyte scientists for tertiary education (Jenkins, 1989, p. 38). The launch of the Soviet satellites at the end of the decade provided the socio-cultural crisis that concerned scientists needed to strengthen their lobby for increased funding towards the development of "discipline meaningful" science curricula; obsolete textbooks, equipment and learning models needed to be junked and replaced with an updated package that was both interesting to the student and served the needs of the scientific community.

In response to the scientists' call and following the success of earlier mathematics education curriculum changes (Posner, 1992, p. 57), numerous American science curriculum development projects were initiated beginning with the Physical Science Study Committee (PSSC) in 1959. Soon to follow the physicists' program development were the chemists and biologists with similar curriculum programs (e.g. ChemStudy, Biological Sciences Curriculum Study). The Nuffield Science Teaching Project and the Nuffield Secondary Science Project were similar science curriculum changes undertaken in the United Kingdom. Adoption of similar programs occurred in Australia; an Australian BSCS package was developed by the Australian Academy of Science; a text *Chemistry: Experimental Foundations*, produced in Australia was based on the ChemStudy model. All of these programs placed considerable emphasis on the assumption that to understand science, students must "engage in the steps of scientific enquiry" (Wheeler, 1967, p. 141). Learning facts about nature was no longer an adequate science education.

The implementation of these types of programs greatly strengthened the structure of the disciplines approach to science education. Many of today's scientists went through school under the auspices of these programs. The success of these, however, cannot be assumed by the success of the small percentage who later became scientists. The vast majority of students who participated in these programs did not become scientists; these students, the adults of today, do not possess significant scientific knowledge nor understanding as witnessed by the considerable popularity of pseudoscience myths such as astrology, numerology and creation science. Not only though is the knowledge about science generally poor, but the public attitude towards science is not positive (Fort, 1993). Even within the academic population, the science disciplines are often held in low regard to outright disdain by practitioners in other disciplines (Harding, 1991). Contrary to previous beliefs, today's adults do not believe that scientists can solve current problems nor do they implicitly trust their endeavours.

And here lies a paradox. There also exists an underlying belief that the future of our economy (to a lesser extent democracy) depends upon children receiving a good education in and understanding of science (Fisher, 1992). Science is seen as a body of empirical, practical knowledge that should be useful to everyone. Scientific education, especially in the physical and applied sciences, is seen as a necessary investment for future economic growth and development (Feldman & Atkin, 1993). However, enrolments of high achieving secondary school students in tertiary science courses are low when compared to the great increase in numbers undertaking study in fields such as law, business or medicine. Most bright, creative students do not see science or technology as offering a desirable and rewarding career.

With these factors in mind, a rethinking of science curriculum is being undertaken around the world with primary focus on possible change within the secondary education sector. Syllabus reviews have, for example, been conducted in the United States (Project 2061; Scope, Sequence and Coordination of Secondary School Science), Canada (Science, Technology and Society interrelationships emphasised in provincial syllabus documents), England (Cambridge Examination Board's Module Bank System comprising 27 integrated science and society units), Sweden (Mandatory science subjects within all post-compulsory courses which highlight links between school, work and continuing education).

The future of science education is of considerable interest locally. The Queensland Board of Senior Secondary School Studies, the statutory body responsible for accreditation of senior secondary school subjects for the purpose of tertiary entrance, commissioned the SSFD Project to collect data and analyse documents concerning the future direction of science education in this Australian state. Issues that need/must be considered for the design of future science curriculum as well as the tensions between seemingly contrasting purposes of the different interest groups were to be identified. A new paradigm for science education was sought which took account of contemporary societal issues.

METHOD

The changing social context of senior secondary schooling, considerably higher retention rates and the vaguely defined relationships between school, TAFE and university provided the framework for the data collection. Parallel questionnaires were administered to teachers (731), tertiary science and engineering educators (40) and senior science students (609). The questionnaire sought views about the purposes served by senior science education and the suitability of the design criteria of current syllabuses and possible future initiatives. After the production of a preliminary report of these results, teacher meetings were held at seven sites throughout the state. Submissions from industry and business were also invited and received. A more detailed discussion of the research method is available in the final report (Beasley, Butler & Satterthwait, 1993).

THE EMERGING ISSUES

The data collected were organised into three categories: the needs of the disciplines, needs of society and needs of the individual student. These are represented in Fig. 1; in the figure, the triangle on the left represents present senior science syllabuses with discipline knowledge largely driving the syllabuses' structure. The triangle to the right represents a syllabus pattern that is more in balance with the current demands of individual students and society. Although each of these categories are discussed separately, all of these issues are interrelated and need to be considered collectively when designing future science syllabuses. Within each category, the report recommendations from the questionnaire data are presented first; these are followed by a more detailed discussion.

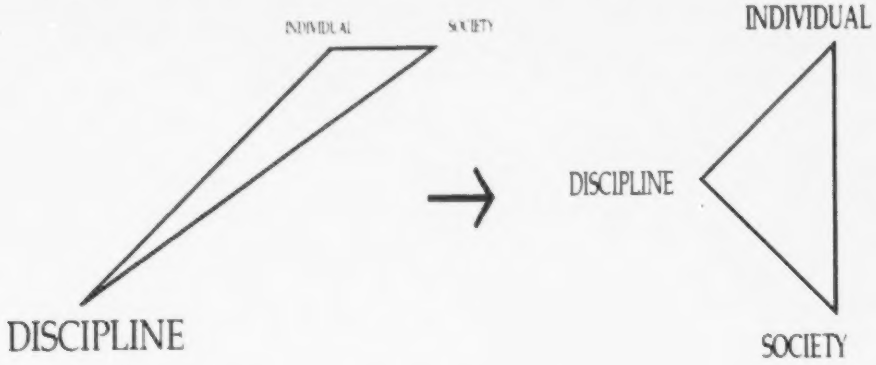

Fig. 1 Two syllabus patterns.

Needs of the disciplines
Emerging issues

1 Alternative syllabus design formats.
2 The clarification of the complementary relationship of core and options in school-based curriculum.
3 Ensuring the role of the laboratory and field experiences in the learning of science.

Most Queensland teachers consider that one outcome of the current senior science syllabuses is to prepare students for university study (76%). Senior science students (66%) also view these courses as preparation for university. And over 90% of the tertiary science educators feel that senior science should ideally serve in preparation for university success. This is not surprising since the syllabuses were originally designed with the university pathway in mind.

University academics set the subject matter of the science courses in a pattern established either directly through the curriculum projects of the 1960s, or indirectly through the beliefs held by the teachers acquired through such projects in their own education. Both share the ideas that in the past senior science has served as a prerequisite for university entrance and success. Ironically, only 40% of those same tertiary science educators believe that the present syllabuses prepare students for university science courses, rather than more generalised university study. Perhaps they view the current secondary science curriculum only as a filter, not as a foundation for further academic study as suggested by Collins (1992).

The alternative tertiary pathway, i.e., entrance into the TAFE sector, is not seen to be catered for in senior science syllabuses; only 45% of teachers, 28% of students and 35% of tertiary educators feel that the needs of students later choosing TAFE are meet. "The world of work" is not seen to be addressed in senior science either. A much smaller percentage of teachers (20%), students (12%) and educators (21%) indicated that vocational needs were relevant to the syllabuses.

However, most teachers (77%), students (72%) and tertiary educators (82%) feel that specialised syllabuses should be available for those who are university bound. They also feel that the syllabuses should be organised around single disciplines rather than be of an integrated or thematic approach (teachers, 72%; educators, 47%; students, 51%). Note, however, that the students and tertiary educators were somewhat less in favour of the more traditional approach.

Students (52%) and their teachers (51%) recognise that a reduction in the compulsory topics would allow more in depth learning to occur. Tertiary educators are less decisive; 37% agree, 32% disagree and the remainder is undecided. Practising scientists have very traditional ideas about science and science education (Pomeroy, 1993, pp. 266-267). Most feel that there is considerable information to learn (rote learning of facts from texts or in lecture presentations), and the key to the development of scientific literacy is achieved through increasing students' ability to read science texts and articles.

Needs of society
Emerging issues

1 Accepting responsibility to design syllabuses to cater for all students.
2 The integration of the science-technology-society nexus into all science syllabuses.
3 Integrating computers into learning settings.
4 The links between school and TAFE and school and employment in new generation syllabuses.
5 The reduction of the compulsory content.
6 Expanding the syllabus treatment and explanation of government Equity and Social Justice policies.
7 Developing and explaining assessment technologies which provide for the intellectual and practical clarification of the categories of syllabus objectives.
8 Produce supplementary materials which clarify the intent and the desired practices inherent in syllabus documents.

The size of the post-compulsory cohorts has increased greatly over the last five years with the expectation of 90% of the total year 10 cohort remaining at school for years 11 & 12 by the end of this decade. This represents a considerable change in clientele; previously students who completed the senior years were amongst a small, select population that anticipated attending a tertiary institution, specifically a university or a college of advanced education. With the change in the composition of the senior school population has come a need for re-evaluating the design of the senior syllabuses.

The senior science syllabuses (biology, chemistry, physics and earth sciences) were designed originally with the needs of the academic disciplines as a focus. The conceptually-based structure of these syllabuses, especially the physics and chemistry syllabuses, is seen to be less relevant to students who do not later participate in a tertiary science course. Senior science school subjects now need to serve a more diverse group of students who want science to be a worthwhile, socially relevant area of study.

Perhaps this can be achieved through a concepts in context approach, e.g. embracing a science, technology and society organisational framework. Secondary teachers (78%), students (77%) and tertiary educators (74%) agree that the role of science in the development and use of technology has a place in future syllabus design. As well, teachers (79%), students (67%) and educators (84%) feel that computer usage should integrated into senior science education. Current science topics, usually of a highly technological nature (e.g. genetic engineering, superconductors, global warming) should also be included in the senior science subjects (teachers 89%; students 90%; educators 74%). When these responses are considered along with an agreed ideal purpose of science education viz., to produce scientifically literate adults (teachers 93%; students 77%; educators 92%), it seems appropriate to examine this possibility.

Teachers and students do not see the current academic discipline subjects producing vocational skills, nor do the majority see a obvious link between the subject and TAFE study. Business and industry groups, however, do see this linkage as a major function of secondary education and have made a considerable push for the recognition of "competencies" or skills to be identified and developed in particular subjects that would relate to 'the world of work". This has become a feature on the political landscape – providing a utilitarian rationale for the retention of students in schooling. The concept of performance standards which represents an outcomes-based approach impose a 'marketplace' atmosphere on senior schooling (clearly defined criteria in which students can be rated or schools be held accountable) are central to curriculum decisions. If senior science education was to serve 'this master', current science teachers would need some convincing of its worth (only 20% agreed with this goal).

Over 80% of the tertiary educators felt that science should be continued into years 11 &12 as a compulsory subject with a variety of differently designed options available; a much smaller percentage (58%) of teachers agreed with the options. However, the secondary school science teachers feel very confident of teaching a science syllabus which is designed with an alternative approach.

The next four issues raised (5-8) should be discussed together because the last three can be seen to be dependent upon the acceptance of the first of this grouping. There was some support by the Queensland teachers for the reduction of the compulsory content of the senior subject (46%). This issue would need to involve a trade-off between content coverage and meaningful learning that emphasises higher order thinking skills, critical reflection on attitudes and beliefs and the integration of the subject with other subjects (e.g. computing, mathematics). Over 97% of the teachers and 90% of the students indicated that critical thinking skills are desirable outcomes of a science education.

A reduction in compulsory content would also allow time to be allocated to social justice issues. These policies could be addressed in a pedagogy that evaluated scientific discoveries and technological innovations within a cultural context, incorporating a science, technology and society approach. If society sees these issues as significant for the future of this country, then current curriculum design priorities must be reassessed. Significant commitment towards the in-servicing of staff would be necessary for this implementation since a significant number of teachers viewed equity issues as being not important (44%). Lastly, the need for an appropriate assessment technology which reinforced the rationale and global aims of the syllabus was rated highly. For example, Victoria has produced effective course support booklets that forge the vision from rationale to assessment and its implementation.

Needs of the individual

Emerging issues

1 Continually updating senior science syllabuses with current science topics, emphasising Australian scientific achievement.
2 Promoting student responsibility for learning.
3 The explicit incorporation of thinking skills within the learning context.
4 Expanding attitudinal and values dimensions of syllabus goals.

Over 90% of teachers and students felt that it is very important that the syllabuses be continually updated to include current science trends; about 80% of tertiary educators also felt that this is very important. The introduction of new, exciting ideas and achievements could serve as both a motivational strategy as well as a providing a dynamic model of scientific enterprise. To a somewhat lesser extent, the three groups also felt that it is very important that Australian scientific achievement be included in the science syllabuses. Tertiary educators voiced their concern, however, that the discipline subjects should concentrate on the building of a solid foundation of basic knowledge; a little of current topics or Australian science "...could be used as spice, small doses to improve the flavour."

Students want to take more responsibility for their own learning. Over 90% of students felt that they should have opportunities to develop critical and abstract thinking skills, undertake analysis of data to solve real problems and learn skills to make responsible decisions. Only slightly less (82-88%), indicated that group problem solving tasks, independent investigations and problem solving assessment should also be incorporated into science education. Language and library skill development rated a majority of 76% and 75%, respectively.

The introduction of language instruction, thinking skills and problem solving are seen as 'add-ons' by most tertiary educators and many of the science teachers. These are often viewed as a wish list for science education that are desirable in principle, but not realistic because of the time constraints associated with course coverage requirements. Laboratory exercises or 'hands-on' activities are usually seen by teachers as a means of reinforcing 'factual' material. Students see these activities as a break from didactic lessons; 92% of students wanted variety, exposure to a wide range of learning settings, including group discussions, laboratory work, library research, fieldwork.

Little attention is currently focused on affective objectives in the senior science syllabus even though teachers (97%) and students (91%) felt it was important to do so. Evidence of this discrepancy is seen in the relatively low ranking of senior science subjects against the students' other five subjects despite science not being a compulsory subject and in the few senior science students who major in science, especially a physical science, at a tertiary level. Just over half of the teachers and students see scientific knowledge enhancing enjoyment of leisure activities like bushwalking or photography; only 21% of tertiary educators agree with this aim. The development of a positive attitude about learning, especially about the natural world, a sense of curiosity and the valuing of scientific questioning (i.e., the asking of questions in a manner where a method of obtaining a solution is achievable) are often listed as aims or goals in science syllabus documents. However, it appears that these are not implemented.

Field studies and independent investigations could provide an excellent context for the development of affective aims. Rated highly by students (93%), field studies could integrate environmental appreciation exercises into other types of field tasks. Independent or group investigations provide a model of how career scientists operate.

CONCLUSION

Adolescents today face an uncertain future. They are deeply concerned about the environment and the social application of science through technology, and are directly concerned about their future employment. As in other segments of society, they also display a very utilitarian attitude towards schooling. Students sense a worth in science subjects in so much as it can lead to becoming better informed about global issues like the greenhouse effect, ozone layer thinning, oil spills and see science as a subject that can lead to bigger and better things such as a means of gaining university entrance. However, less than 20% see science as directly helping them prepare for a job or career. Their teachers do not see the current discipline subjects leading to jobs directly, nor do the majority see a link between the subject and TAFE study.

The Senior Sciences Future Directions Project has attempted to define the issues that must be considered upon the rewriting of the Queensland science syllabuses. Expectations of society and the individual student are different now. These two stakeholders make many demands on schooling in general and have begun to have considerable influence on science curricula. Science curriculum designers cannot just add on to the already heavy knowledge component prescribed by the disciplines but need to satisfy these other interest groups as well; science subjects need to be redesigned, reconceptualised. Australia, with its range of syllabus design formats should prove to be an excellent testing ground for this reconceptualisation.

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CONCEPTIONS OF WATER-RELATED PHENOMENA

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ABSTRACT

Water is an important resource. Surprisingly, research into students' conceptions of water has been confined largely to studies of change of state. This paper reports the results of interviews about underground water, water pollution, the water cycle, and change of state). There were 45 students interviewed about these phenomena: all were in Year 9 or Year 10 in Western Australia from three schools, two country, one metropolitan. In addition, 715 students in Years 9 and 10 in five government schools, three metropolitan and two country, completed a teacher-made, water topic test. Students appear to have a good understanding of some water-related phenomena, such as the water cycle, but have conceptions about other phenomena, such as the water table, which are not in accord with scientific views. As others have reported, interviews reveal that students often use scientific language without understanding.

INTRODUCTION

As in many other parts of the world, water in Australia is not an unlimited resource. In the Perth Basin of Western Australia, a rapidly growing population will continue to compete for this finite resource. Important decisions concerning the management and use of water resources can best be made in cooperation with the community. The nature of such cooperation may well be determined by the level of understanding about local water resources.

There are several different interest groups that have specific concerns with water and water resources. These groups include state-wide non-government agencies such as the Conservation Council of Western Australia; specific water interest groups such as the Wetlands Preservation Society; and, the Australian Conservation Foundation. State government bodies which have a direct interest in this area are the Water Authority of Western Australia, the Waterways Commission and the Environmental Protection Authority. All of these groups receive inquiries from the community members about water. The Water Authority, being the principal supplier of water, provides a lot of information on water issues to the public and has become increasingly aware of its accountability to the public. Nancarrow and Syme (1989) suggest that there has been increasing interest within major water authorities in the level of public understanding of water management issues.

Past research findings (Zube, Vining, Law & Bechtel, 1985; Happs, 1986) suggest that general levels of community scientific understanding concerning environmental problems are likely to be low. Environmental decision-making, not surprisingly, tends to be mediated by the pre-conceptions held by individuals (Ghiselin, 1982); this is consistent with current knowledge about information processing as described in the "constructivist" literature (Wittrock, 1981; Strike & Posner, 1984).

The materials available and currently used in schools regarding water are often general in nature, with limited attention being paid to the particular problems of a local community. In addition, available materials may be unsuccessful in bringing about a change from general community conceptions to scientifically acceptable conceptions.

A joint project between the CSIRO Division of Water Resources and Murdoch University was initiated to investigate conceptions of water and water-related phenomena among a sample of high school students. Two research questions guided our work, one substantive, the other methodological:

- What are some common student conceptions about water-related phenomena such as change of state, water pollution, the water cycle and underground water?
- What are some fruitful probes of student conceptions of water-related phenomena, particularly suitable for classroom teachers?

PREVIOUS STUDIES

Probes of student conceptions

Carr (1991) noted the emphasis over the past decade on qualitative methods which probe what students actually think, as opposed to testing students on aspects of a concept that they are presumed to know about. Among these methods is the interview, which has been used in research on personal construction for many years. Piaget also used a clinical interview technique with children to understand their ideas on several areas of physical science, including some properties of water (Piaget, 1929). More recent applications of interview methods, including Interview-about-Instances and Interview-about-Events procedures, according to Carr (1991), provide for a "focused conversation about external stimuli, and concentration on them removes the oppression of eyeball-to-eyeball confrontation. The focus materials are deliberately familiar and 'real world' so that responses are triggered from contexts outside of, as well as within, the school, laboratory or classroom." (p. 17)
Both procedures have been used to explore frameworks held by science students around the world.

The amount of time taken to conduct each interview is a major drawback of the method, as it is difficult to establish reliability and validity of data unless the process has been trialed and modified accordingly. Hill and Wheeler (1991) used the Interview-about-Instances procedure to elicit students' ideas on scientists, science and technology. They found that "reliability was influenced both by the number of illustrations used and in their order of presentation" (p. 127). As teachers generally do not have the time for extended interviews, we explored the use of a questionnaire on water-related phenomena in addition to interviews with a sample of 45 students. The statements in this questionnaire were derived from the literature, reviewed briefly below, and from student interview transcripts.

Student conceptions of change of state

In reviewing studies that address students' perceptions of water, it is important to note that few have been completed in Australia, even though Australia has major water concerns. Studies on water-related phenomena have focussed on student conceptions about changes in state (Bar, 1989; Osborne & Cosgrove, 1983; Russell, Harlen & Watt, 1989; Mangan, 1992). Few studies have involved children's understanding of the complete water cycle or underground water. Bar (1989) reported that children's understanding of certain water-related concepts was a function of age. Her conclusions were based on interviews with Israeli children aged 5 -15 years. For example, children's conceptions of evaporation could be categorised into one of four age-related views, as follows: (1) the water disappears (age 5-6); (2) the water penetrates solid objects (7-8); (3) the water evaporates into some "container" (9-10); or, (4) the water evaporates, it is scattered in the air (age 10-11).

Russell et al. (1989) investigated the views of a sample of UK students aged 5 to 11. They also reported an age-related difference in students' conceptions of evaporation in two of the three experiments that the children in their sample completed. In one of the experiments, the students had to explain the evaporation of water from a tank. The majority of the youngest age group (aged 5-7) did not mention conservation of the water, nor change of phase, but instead focused on the water that was left in the tank. In the two older age groups (8-9 and 10-11) the most common response to the water's disappearance from the fish tank was that the water moved in "unchanged form" to a remote site; this view increased with the older (10-11) sample. Osborne and Cosgrove (1983) used the Interview-about-Events method to gain insights into the conceptions held by children aged between 8 and 17 years on boiling, evaporation, condensation and melting. They found that students appear to understand these phenomena and to be using the correct words to explain them, but when asked what specific scientific words mean, the same students had "no sound scientific concepts underpinning these labels" (p. 836). In some cases, non-scientific ideas may actually increase with age as students learn more 'science words' and apply them incorrectly. For example, some of the older students in their sample thought that bubbles in boiling water were made of elemental oxygen and hydrogen.

Driver, Guesne and Tiberghien (1985) support this limited use of scientific language: they found that "pupils added the words 'conductor' and 'insulator' to their vocabulary without substantially changing their ideas about heat transfer" (p. 198). It has been suggested that one reason for the confusion of scientific terms and the actual process that they describe is that so many words used in science are the same words that are used in everyday language, only that they have a slightly different meaning (Gunstone, Gray & Searle, 1992).

Ideas at odds with accepted science ideas may arise from the way that children tend to base their reasoning on things that they can observe (Driver et al., 1985). Similarly, Russell et al. (1989) suggest that "children are susceptible to focussing on very particular attributes of any given stimulus material" (p. 575): this could have important implications in the way that stimulus materials are chosen.

Finally, there is evidence which suggests that even after formal science learning, the conceptions that the students hold before instruction continue to be the conceptions that they use to interpret phenomena (Gunstone et al., 1992).

METHOD

The first approach in eliciting student conceptions of water and water-related phenomena was the Interview-about-Instances technique, which has been widely used in research on students' views on a range of science phenomena. In this study, students were shown a series of eight line diagrams with captions relating to water phenomena. A question, which was the picture's caption, was read. Each question was designed to elicit the student's knowledge in a specific area, such as ground water, rain, lakes or domestic water use. For example, one diagram showed a line drawing of a lake in the middle of winter with water in it, and the same lake in the middle of summer with no water in it. Below the diagrams were two questions: Why is the water no longer there in summer? Where has it gone?

The second approach was a Water Questionnaire, which comprised 34 statements about water. The statements, which were derived from the initial set of student interviews, as well as the limited previous research in this area, were grouped into clusters of four or five statements that related to a theme. Respondents were required to rate each statement on a scale from 1 to 5: 1 corresponded to 'I am sure this is right'; 3 corresponded to 'I don't know if this is right or wrong'; 5 corresponded to 'I am sure this is wrong'.

The third approach was to administer a teacher-made test on water to test students' understanding of school science, as teachers rely on such data from their own testing programmes. There were twenty questions taken from end-of-topic tests on water from a number of schools. (These end-of-topic tests are administered to students (usually in Year 9) who have completed the elective science unit, Water: The essential fluid at these schools.) To this set of twenty questions, we added three multiple choice items from Osborne and Cosgrove (1983). These three questions were based on student responses to interviews, and probed student understanding of evaporation phenomena. They allowed us to make direct comparisons with New Zealand data.

SAMPLES

Students from five different schools were involved in the study. Each school was approached (and agreed) to take part in the study. The secondary student population at each school was, respectively: Deionised, 1021; Aqua, 977; Evian, 402; Distilled, 259; and, Perrier, 50 students. Two were schools in the metropolitan area of Perth, Western Australia (Evian and Deionised); the remaining three schools were outside the metropolitan area (Aqua, Perrier and Distilled). All five were government schools.

Students from Years 9 and 10 were chosen for the study. In all, 45 students were interviewed: 18 Year 9 students and 27 Year 10 students (from Aqua, Perrier and Deionised schools). The multiple choice test was completed by 715 students, and the Water Questionnaire 660 students.

RESULTS

Interview Data

The interview transcripts were analysed using a conceptual inventory method, described by Griffiths and Preston (1992). These authors used the inventory to establish students misconceptions; however, this method was modified to determine conceptions that the students held, regardless of whether they where "scientifically correct" or not.

The most common conceptual categories were then established and the responses from each interview question were grouped where possible so that the students conceptions could be viewed against the original instance in the interview. A descriptive summary of the conceptions that emerged and the frequency with which they appeared was compiled. After the initial analysis, it was found that there were few significant differences in the frequency of conceptions held by students in the three schools, but there were some differences between Year 9 and Year 10 students.

Evaporation. Several question in the interview were designed to probe student's knowledge of evaporation. Most students said that water from a puddle might evaporate, as would rain that had fallen. Most suggested that water from a lake or puddle would evaporate and go up to form clouds. These results are consistent with the findings of Bar (1989), who reported that the oldest children in her sample (age 10-11 years) believed that water from a tank evaporated and scattered in the air. These students were aware that the water had changed form, from a liquid to a gas, as did the students in the Western Australian sample, although these students are several years older than the students in Bar's sample. The older students in the study reported by Russell et al. (1989) were of a similar age group to those in Bar's study, but they found that the students believed the evaporated water had moved in "unchanged form"; that is, the water had not changed phase to change location. However, the students from both of these groups are much younger than the students used in the Western Australian sample.

Water Cycle. The majority of students in the sample had some knowledge of the water cycle. While most of the answers given were scientifically correct, students often appeared to use the scientific terms without understanding. Answers to questions about boiling water and evaporation of water from both a puddle and a lake, showed that students had scientifically correct conceptions about the process of evaporation. This view was further consolidated by the responses that the students gave to the questions about the clouds and rain. The students in the sample most commonly said that rain was made of water droplets, water vapour or evaporated water, and that before the water had formed clouds it was water on the ground or in the atmosphere. Almost all of the students knew that the rain that had fallen would end up being evaporated at some stage, therefore completing the cycle.

Underground Water. Students appear to be confused about underground water. For example, a common answer on a question on what would happen to water in a puddle was that the water would quickly soak down to the water table. Students knew that bore water came from the water table, but there were differences of opinion as to how the water would get out of the water table. The majority of Year 10 students said that the bore water was pumped to the surface. Year 9 students either did not respond or said that natural pressure in the ground forced the water to the surface. Another question probing this area concerned a leaking petrol tanker. Students suggested that the petrol would either evaporate or soak into the ground, and that the petrol that does sink into the ground could affect the water table.

Boiling. The question on water boiling in a saucepan was, at least in part, well answered by most students. The majority of students suggested that the water would evaporate and become water vapour or steam, which would rise to the ceiling and then condense and form water droplets. Students may have been able to answer this question well because it is readily observable at home (supporting the suggestion of Driver et al. (1985), and some students may have completed a similar task in school science. Students, however, appear confused about the composition of bubbles in boiling water. Although the most common response was air, a variety of other responses were also given such as [elemental] oxygen, steam and [elemental] oxygen and hydrogen.

Pollution of Water. Two questions were designed to investigate students' knowledge of water pollution issues. The first was a question about algal growth in summer. The most common conceptions that the students held about algae were that algae grow more in summer than winter and that algae needs "run-off" to bloom. Some students were not clear about what algae actually are: among the responses were pollution, seaweed, bacteria or chemicals. A few students thought that the algae would grow more in winter because of the increase in water supply. The other question that addressed water pollution was the leaking petrol tanker. As stated previously, while some of the students knew that the petrol could soak down to the water table, few students saw this as posing any real threat to the water supply, and those that did mention water supply said that this water would only be used for gardens.

Water Test

Scores on the twenty questions of the water topic test ranged from 0 to 19; the mean was 11.0, with a standard deviation of 3.6. Just over one quarter (27 per cent) of the sample scored 9 or less. The internal consistency of the test (coefficient alpha) was 0.67. Discrimination indices for twelve of the twenty items were 0.4 or greater, with five of those twelve items 0.5 or greater.

Water: The essential fluid is an elective science unit taken by some students in Year 9 or, less commonly, Year 10. Interestingly, the mean score for the 24 per cent of students who had studied this unit was 11.8 compared with a mean of 11.0 for those who had not studied the unit. This difference was not statistically significant. Similarly, there was no statistically significant difference between the mean score for females (48 per cent of the sample) and males. It may be that students who had done the unit had forgotten some of the material they had learned that was specific to the unit. Some ideas (such as change of state) are reinforced in other units, which provides an opportunity for revision.

Change of state
Three multiple choice questions were based on earlier work by Osborne and Cosgrove (1983). Of our sample, 41 per cent incorrectly thought that the bubbles in the boiling water question were made of elemental oxygen or hydrogen. Just over half (52 per cent) of the students answered the question on evaporation correctly: water would become "bits of water in the air". However, 33 per cent of the students said that the water would "change into oxygen and hydrogen in the air". Finally, 35 per cent of students chose the correct answer to the question on condensation, that water in the air sticks to the outside of the glass jar; 41 per cent chose the incorrect answer that condensation on the outside of a glass of ice was caused by coldness making oxygen and hydrogen form water. Over 30 per cent of students chose the answer that mentioned elemental oxygen and hydrogen, even thought they were the wrong answers, in all three questions. It is possible that, as Gunstone et al. (1992) suggest, students are answering with what appeared to be the most 'scientific' answer of the three choices.

Water Questionnaire
Frequencies of responses to each statement were computed. A number of models were specified and confirmatory factor analyses (Jöreskog & Sörbom, 1989) conducted to test these models. None of the models was congruent with the data, which suggests that the students in this sample do not have well-defined conceptual structures about water-related phenomena. Responses to individual items, however, can provide teachers with useful 'snapshots' of student conceptions.

CONCLUSION

Osborne and Cosgrove (1983) suggest that many students appear to understand scientific concepts by using the correct scientific terms when discussing concepts, but cannot elaborate further when probed. This was confirmed in our study. In particular, students appear to focus on [elemental] oxygen and hydrogen in questions about water, no doubt because they remember that water is H_2O. This leads some of them to look for these two elements as cues to the perceived correct answer.

The interviews provided valuable insights into the students' conceptions of water- related phenomena. However, such interviews are time consuming. For classroom teachers, the 34-item water questionnaire may provide an alternative (even if limited) probe to the more time-consuming interviews. Frequencies of student ratings of the 34 statements can provide an indicator of students' certainty about the conceptions they hold. The multiple choice question approach is another alternative. We have recently developed a set of multiple choice items based on student interview data. These items, like the three from Osborne and Cosgrove (1983) may provide another probe into student understanding which will be of benefit to classroom teachers.

A recently-published variation on these approaches is to combine the multiple choice format with ratings. Rowell, Dawson and Madsen (1993) suggest offering students a multiple choice format in which students rate each response, rather than choosing one response only. This approach is similar to our Water Questionnaire approach. These varied approaches can, together, contribute to our understanding of conceptions of important physical phenomena, in this case, water-related phenomena. Some of these probes may be of particular use to classroom teachers.

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A STUDY OF FORCE CONCEPTS IN TERTIARY LEVEL STUDENTS

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ABSTRACT

This paper reports on the application of a constructivist-based teaching strategy with a small group of first-year physics students. Data collection and analysis procedures are discussed, and the responses of three students to three situations involving force concepts are presented. A number of issues relevant to conceptual change teaching strategies are identified. In addition to an emphasis on alternative conceptions, issues identified that require consideration when developing teaching strategies for conceptual change include an emphasis on understanding physics terminology, the development of a supportive learning environment and the use of a wide range of problem contexts.

INTRODUCTION

Research into student alternative conceptions has established three main factors concerning their effect on understanding (Clement, 1987; Helm & Novak, 1983; McDermott, 1984). Firstly, it is clear that alternative conceptions are not simply misunderstandings, secondly that they are strongly held by students, and finally that they are barriers to a meaningful understanding of physical phenomena. Based on these three assumptions about alternative conceptions, the research described in this paper describes an attempt to promote meaningful understandings through the use of a teaching strategy designed to achieve conceptual change. The investigation was a classroom-based study of a group of seven students that comprised the whole class in the subject Applied Physics, in which the author acted as both teacher and researcher. This paper reports the findings of a study of force concepts, and is part of a wider study of conceptual change conducted by the author (Searle, 1993).

THE STUDY

As well as assuming the three characteristics of alternative conceptions listed above, the investigation was grounded in a constructivist approach to learning (Osborne & Wittrock, 1983; 1985). Briefly stated, the premise is that students are active learners who construct their own understandings of phenomena on the basis of context and their present state of knowledge.

The role of the author in the research programme was a dual one. On the one hand, the teacher role involved presenting content using strategies that encouraged learning and understanding. The other role was that of the objective researcher observing individual and class interactions to collect information from which judgements about student ideas and thought processes could be formed. As one role involved the promotion of understanding and the other obtaining measures of the effectiveness of the promotion, the two roles were somewhat in conflict. The question however is not so much whether there is an interaction between the two roles, but whether there is an awareness that the interactions that do occur need to be considered when data is interpreted. In naturalistic research studies of this type the boundary between research and teaching is often blurred, and recognition of this fact is necessary to place the learning outcomes in context.

Participants
The seven students who took part in the study were in the first year of a two-year course in Scientific Instrumentation at a rural college of advanced education. All students except one had passed a physics subject at Year 12 level and two students were repeating Applied Physics. The ages of the students ranged from 18 to 27, with the youngest coming directly from secondary school and the remainder either returning to study or repeating the subject.

Teaching Strategy
In order to achieve and be aware of conceptual change, it was important that students knew what their ideas about a particular topic were to begin with. The first of two broad aims for the teaching strategy was to make students aware of their own ideas, as well as those held by other students in the group. This technique of allowing students to become familiar with the ideas of others was designed to expose each student to a range of interpretations of physical phenomena apart from their own. Through this heightened awareness of alternative explanations, it was envisaged that each student would think more deeply about his own views, and either modify, discard or hold on to that view. The second aim of the strategy was to promote conceptual change (where alternative conceptions existed) to a scientific view. The ability of students to solve "real world" physics problems, as well as standard physics textbook exercises, was used (in part) as an indicator of the success of any conceptual change.

These broad aims of the teaching strategy were to be realised via three stages. The first was the introduction of a topic or concept via a POE (Predict-Observe-Explain) experiment or demonstration experiment. The POE strategy has been used by a number of researchers in science education to determine student alternative conceptions (Champagne, Klopfer & Anderson, 1980; Gunstone & White, 1981; Searle, 1986). The focus in this study was to use the POE technique not simply to uncover the range of student ideas about a concept, but to use these ideas as a vehicle for discussion aimed at conceptual change.

The second phase of the program was the use of qualitative problems related to the concept under consideration. Qualitative problems were used in general class discussion with further problems allocated for homework or revision purposes. The class analysis of non-mathematical problems served to reinforce and apply the scientific view generated via the POE experiments and subsequent discussion. Furthermore, the consideration of phenomena from a qualitative perspective could be used to uncover and challenge additional alternative conceptions that may not have become apparent in previous discussions.

The first two phases of the strategy were designed to provide strong basic principles from which the more conventional quantitative physics problems could be tackled with confidence: the third phase of the strategy, in which quantitative problems were introduced via a worked example (or examples) provided by the teacher. Textbook problems of graded difficulty relevant to the concept under consideration were set for homework and tutorial sessions.

Two key elements present in all phases of the strategy were an emphasis on a qualitative approach (initially at least) to the solution to problems, and on the verbal expression of student views. Students were expected to explain their reasons for a particular viewpoint or problem-solving strategy. As indicated previously, student awareness of their own concepts is an important precursor to conceptual change. Furthermore, the ability of an individual to apply a concept in the successful solution of a qualitative problem was regarded as a valid indicator of an understanding of that concept. Through articulation of their ideas it was hoped that a deeper understanding of concepts would occur, thus making the transition to a scientific view more likely.

Data Collection

The concern of the author was to investigate what was happening in the physics classroom with regard to conceptual change, and gain an understanding of the mechanisms involved. In order to investigate adequately the interactions occurring in the classroom, as well as the actions of individual students, the naturalistic case study approach was adopted. Easley (1982) has argued that educational research would be more useful to classroom teachers if it were in the form of naturalistic case studies, and oriented toward discovering the mechanisms that underlie the learning process. Thus the case study approach used in this research was legitimate not only as a research tool for the area under investigation, but also for its anticipated usefulness to classroom teachers.

The focus of all the modes of investigation outlined below was to obtain information about the thoughts, ideas, actions and reactions of each individual in the group. It was anticipated that an analysis of the information about each student would provide an insight into his learning processes, as well as the mechanism of conceptual change.

Audiotaping of Classroom Sessions. As the class size was small, it was possible at the start of each class to rearrange the classroom furniture from the normal linear array of chairs and tables, to an "open square" format. This format enabled each person to have eye contact with other members of the group, a factor that would allow discussion to occur more freely than in the normal classroom arrangement. It also promoted the role of the teacher/researcher as a member of the group, rather than the more usual role as an authority figure disseminating information to those able to receive it.

Responses to POE Experiments. Written responses to each POE were collected for analysis, as well as the associated audiotapes of class discussions or individual interviews.

Problem Solving Responses of Students. At the beginning of the research study each member of the group was issued with an exercise book containing duplicate pages. Students were asked to use the books for all problem solving, and the duplicate pages were collected periodically by the teacher/researcher. The original copy was retained by the student for assistance with revision.

Assessment Materials. The Applied Physics subject was formally assessed using a three-hour examination at the end of each semester (each 40% of the total assessment) and five assignments/problem sheets issued throughout the year (20%). Three assignments were completed during the mechanics section of the course. Students had one week to complete each assignment. The written responses to the assignments and semester examination were collected. Qualitative problems were an integral part of the assessment tasks to reflect their importance in the teaching strategy.

Individual Interviews. Interviews of approximately 25 minutes duration were conducted during the teaching programme, usually at weekly intervals. Two interviews were held following the semester examination. The interviews explored students' recollections of previous physics instruction, their strategies used in solving qualitative and quantitative problems, their awareness of conceptual change, and their perceptions of the usefulness or otherwise of the teaching strategies adopted by the researcher/teacher.

Data Analysis

A common problem in qualitative research is that of choosing a method of data analysis that preserves the richness of the data without becoming overwhelmed by the volume of information. The technique adopted in this study to address this problem was to focus on a small number of "Episodes" that exposed student views during the teaching programme.

Each Episode was a whole-class or individual experience that was an integral part of the teaching programme, but chosen for analysis because it provided insights into student views about a particular phenomenon or concept. In most instances the Episodes were derived from one of the probes of understanding such as a POE experiment, classroom discussion or qualitative problem. In order to investigate conceptual change, a small number of students were selected and the Episodes used as markers to plot the changing views of a particular concept with time. Three students (given pseudonyms Dick, Greg and Paul) were chosen for the study as it was felt a more detailed investigation of a small number of students was likely to yield more insight than a less focussed analysis of the whole class. In choosing the three students for the longitudinal study one was selected because he was observed to be having difficulty understanding mechanics concepts, one because he was not having difficulty, and the third for his prevalent usage of previous experiences and intuition in his explanations of physical phenomena. By comparing the three students with somewhat contradictory characteristics, it was anticipated that a deeper insight into the conceptual change process may emerge.

RESULTS

In the more comprehensive study of force concepts (Searle, 1993) a total of 14 Episodes were used in both linear and circular motion contexts. Topics in kinematics were covered in the first three weeks of the programme, and the study of dynamics commenced in Week Four. This paper reports the results from classroom discussions of three linear motion Episodes chosen to highlight a number of issues relevant to teaching for conceptual change. The focus of the teaching strategy was to encourage students to use and appreciate the importance of the qualitative aspects of Newton's Second Law, and in particular that net force is in the direction of acceleration, henceforth referred to as the "primary force concept".

Episode One (Week Four)

The results from Episode One comprised the diagrams and written responses to the sledge problem and a transcript of the class discussion that followed. The written responses are included as Fig. 1.

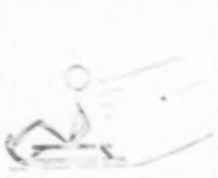
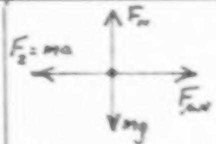
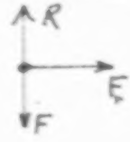
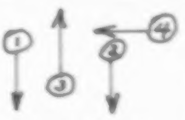
Episode One	Dick	Greg	Paul
 A sledge slides down a hill onto a flat plain. What are the forces acting on the sledge?	 F_1 = force due to gravity F_N = Reactive force F_{fr} = Friction force F_2 = Force mass x acceleration of hill If object constant F_2 = 0	 F is the force due to gravity acting on the sledge. R is the reaction force and F_r is the frictional force which acts so as to oppose the motion.	 1. Weight of body sitting on the sled. 2. Weight of sled against the ground. 3. Ground pushing back against sled. 4. Momentum of the sled.

Fig. 1 Episode One description and student response diagrams

BEST COPY AVAILABLE

Classroom transcript (<–> indicates a section of dialogue has been omitted from the transcript; PS refers to the author):

PS: What are the forces on the sledge?

Dick: Weight down, reaction up ...

PS: Due to the snow, and that's obvious in the case of snow because you can see marks in the snow ...

Brad: F_1 that way. [In the direction of motion.]

Dick: A force going that way [in the direction of motion], friction between the snow and the sledge, and air and that sort of stuff ...

PS: Right, friction due to snow, air, yes ...

Dick: F_1... is one that I can't understand. If that is coming off the hill, and it's on the flat ... If it is on the hill it is alright, but what about when it is just flat ... there is no acceleration, so there is no force [in the direction of motion].

Paul: What about the momentum?

PS: What about momentum?

Paul: Wouldn't that be force enough to carry it on until friction ...

PS: Well, are force and momentum the same? Is momentum a force or ... ?

Paul: I don't know.

PS: I know they are confused in normal language but in physics, momentum and force are two different things. We will talk further about these two later on. <–> What is F_1 then Brad, seeing you suggested it?

PS: Has anyone else got a force going that way? What is F_1 due to? As I was saying before forces must have some sort of cause.

Brad: Velocity?

Dick: The reaction against the friction. If the friction is going this way, there has to be a force going the other way to counteract the force of friction.

Brad: If the friction force is opposite to the force F_1, I don't think it will move. So then F_1 [must be] greater than [the friction force], and F_1 was due to gravity anyway, because it came down the slope.

PS: And now? Now that it is on the flat?

Brad: Now it is due to velocity. Conversion of potential energy into kinetic energy.

PS: What do you think Stan?

Stan: I don't know ...

PS: Did you have a force going that way?

Stan: Yes. I didn't explain why though.

<–>

Mark: There is no force acting forwards [on the sledge] now because it is on the flat. There is no force as such. Before there was, when it was at the top of the slope there was a force down the slope, due to gravity. But now that's stopped so the total force is the resistive force F, which is going to slow it down and pull it backwards, against its momentum. Which isn't a force.

PS: What do you think, Greg? You've been very quiet there.

Greg: Yes, well I agree with Mark. Because if it is due to gravity, the force was down the slope, it will be $g\sin\theta$, and when it gets to the flat, that θ is going to be zero, which means the force will be zero.

Episode Two (Week Four)
In Episode Two, each student was required to indicate and then justify the forces acting on a ball thrown vertically in the air at three different locations during flight. The locations were on the way upwards (A), at the top of its path (B), and on the way downwards (C). The responses in Fig. 2 include diagrams for each of the three locations, but explanations for location A only.

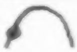
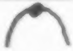
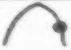
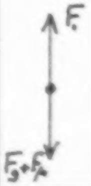
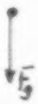
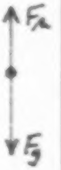
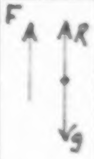
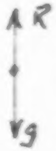
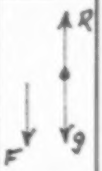
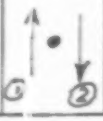
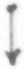
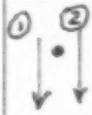
Student	Forces acting			Explanation of forces at Instant A
	 A	 B	 C	
Dick				F_g = Force produced by gravity acting on ball + Force of viscosity of air. F_1 = Force applied by person throwing the ball. The ball is going upwards with force F_g acting upon it. F_1 is force which is pushing it. There is also the frictional force acting down on it, same direction as (g) in this example.
Greg				The ball has had a force exerted on it so as to throw it in the air. Therefore a force acts upwards. A force due to gravity always acts on the object so a force acts down and (R) the reaction force acts in the opposite direction to g. The ball initially travels upwards because of F.
Paul				Forces acting on the ball are: 1. force that threw it up 2. gravity acting downward upon the ball Motion - deceleration upwards.

Fig. 2 Student responses to Episode Two

A classroom discussion of the Episode followed:

PS: Well what did you get for point A, Greg?
Greg: Weight force down, reaction force acting up, and the force that was given to it by the hand to push it up - in that direction [up].
PS: Sorry, this one is due to?
Greg: "mg"
PS: OK, seeing you have started you may as well keep going through [points] B and C.
Greg: R and mg. [Forces acting at point B.]
PS: R is still up?
Greg: Yes. R and mg again same directions. R is still going up and mg is still down.
PS: I've guessed the sizes there, are the sizes OK.
Greg: They're equal.

PS: Equal there [at point A], and there [at point B], and there [at point C]?
Greg: Yes. And I'm not sure, but I think there is a force acting down at C.
PS: Another force acting down?
Greg: Yes, I'm not sure about that. Otherwise it would still be stationary.
PS: Any idea what that [force] is due to?
Greg: Ummmmm, acceleration.
PS: Well going to A first what do you think of that - mg due to weight, R [is the] reaction due to ...?

Greg: Due to ... force of ... air.

PS: It's a frictional type force?

Greg: Yes.

PS: And F_h - force due to the hand. And at the top, F_h is gone?

Greg: Yes, because it is stationary in the vertical direction.

<–>

Dick: At B, at that top part where it is just going to be stopped, I don't think there should be a frictional force acting up, I think it should only be gravity acting down on it ... at that particular instant. When it started moving again it would have the frictional force acting on it.

PS: OK.

Mark: I would have thought that for the entirety of the ball's flight that there is only one force acting on it, and that is the force due to gravity. Because it is out of the guy's hand, it's not being accelerated by anything else, it's only got the force of gravity accelerating it, which causes it to stop at the top, and then speed up again at the bottom before he catches it. If you want to count air resistance then there will be a force ...

PS: Stan?

Stan: See, the ball's travelling up, air resistance is in the opposite direction to its motion, so if it's going up, so air resistance is going to be down.

PS: So you're saying there is weight and air resistance down?

Stan: Yes, and at C, there will be ... weight still down, but air resistance in the opposite direction, because the ball is going down and it would be acting up. And at that one there [B] it is just "mg".

PS: OK. Well what do you think of that, Greg - it is different to yours.

Greg: Ummmm, I agree ...

PS: You agree that it is in the opposite direction?

Greg: Yes.

Episode Three (Week Five)

A POE experiment in Week Five of the programme required students to predict the orientation of a small metal pendulum bob attached to the rear of an accelerating laboratory cart (Fig. 3). The class discussion of the POE experiment began with an emphasis on the forces involved in the motion:

PS: What are the forces acting [on the bob when the cart accelerates]?

Brad: Weight, tension, air friction.

PS: Any others? [Pause] O.K. They are the component forces acting. What is the direction of the net force? Because the net force means the total of all of those, which means one arrow, one vector.

Mark: I'll have a go then. Even though it is contradictory to the picture, it's got to go that way [in the direction of acceleration].

PS: You've got a different answer? [Directed at Stan.]

Stan: Ummmm .... sort of.

PS: Well, did anyone have anything different to that?

Greg: I think I did, but I now agree with [Mark]. I agree with going that way because that is the way the thing is actually moving - even though it doesn't look like it.

PS: Can you remember which way you had [the net force]?

Greg: I think I had it the same way as friction.

PS: You had it that way too? [Directed at Dick.]

Paul: I had mine that way.

Dick: I had it that way too.

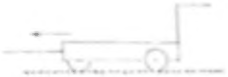
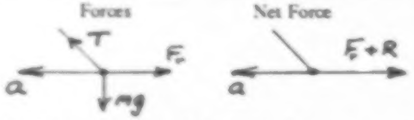
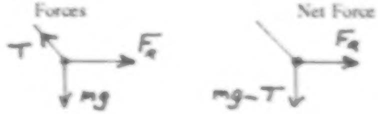
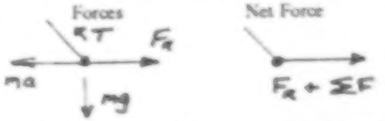
Episode Three	Dick
Indicate the position taken by the pendulum attached to the accelerating cart. Indicate and justify the forces and net force acting on the pendulum bob. 	 Forces Net Force T F_r a mg F_r+R a When the cart is started the ball will move away from its equilibrium position to somewhere in the direction opposite to the cart's acceleration. This is caused by the F_r (due to air) and the reaction force of the cart compared to the ball.
Greg	**Paul**
 Since cart accelerates horizontally and the ball has no horizontal connection to the cart, it is going to want to stay where it is which makes it seem to move in the other direction in reference to the cart.	 There is now a constant force acting on the ball. Air resistance and another force which I don't know what to name will cause the ball to constantly lag behind the trolley.

Fig. 3 Episode Three description and student responses

PS: They're all coming out of the woodwork now! Well, which is right and which is wrong? Because resultant force can only be in one direction, so one of those - unless there is some other possibility - one of them can't be right.

Stan: The force should be in the direction of acceleration shouldn't it?

PS: Why do you think it's wrong? You did it that way, but you're not happy with it? [Directed at Mark.]

Mark: No, I think that's the way it's got to be, because it's moving, it's accelerating that way. The reason it's stuck out there is just due to it's inertia, it doesn't want to change, its resistance to change motion. <->

ISSUES RELEVANT TO CONCEPTUAL CHANGE

Responses to the three Episodes highlight two alternative conceptions as well as three other issues worthy of discussion in any consideration of constructivist teaching strategies for physics students.

Motion implies a force view

It was evident from the written responses to Episode One that a number of students held a motion-implies-a-force view for the motion of the sledge. Paul and Dick included a force in the direction of motion of the sledge in their written responses, although the statements from Dick (and Stan) during the class discussion indicated they were unsure of the origins of the force. For Episode Two, all three students included an upward force on the ball at location A. The justification for the force changed with both the problem context and student and was described variously as the "ma" force, momentum, force applied (by the person throwing the ball), and reaction force. The single characteristic common to the responses and class discussion was an apparent need by the students to include a force in the direction of motion of the object.

Reaction force view

In his attempts to explain the forces acting in Episodes One and Three, Dick used the notion of "reactive force", a force equal to but opposite in direction to the friction force acting on the sledge. Greg also used the notion in his justification of forces in Episode Two; it appears to involve a mis-application of Newton's Third Law. The oft quoted maxim: "To every force there is an equal and opposite force", is stated and accepted by many students without any consideration of what the forces act on. Furthermore, the use of Newton's Third Law to justify the existence of a force provides a degree of credibility to the choice, and subsequently to the stability of the alternative conception. The tenacity of notions such as the reaction force concept is also evident in a recent study by Hestenes, Wells and Swackhamer (1992) who report that difficulties with Newton's Third Law persist even among graduate physics students.

Terminology

In discussing the motion of both the sledge and the ball in the air, a number of students were unsure of the distinctions between the terms force, velocity, momentum and acceleration. This lack of differentiation between physics terms is not uncommon in beginning students of physics (e.g. Halloun & Hestenes, 1985), and is a factor that impedes a full understanding of physical phenomena.

Classroom environment

The class discussion of the sledge problem enabled a range of views to be put forward and analysed. The role of the author (in this instance) was to encourage each student to explain his choice of forces so that the whole class was aware of the range of possible explanations, both correct and incorrect. The discussion strategy requires a classroom environment in which each participant is comfortable in expressing a view without fear of ridicule or condemnation by another member of the group. It also requires members of the group to support their view in order to convince others of its validity and usefulness. That is, each view must be accepted for what it is — a genuinely held belief — which can then be discussed and compared with other views in a dispassionate, but critical manner. For the seven students of Applied Physics the approach was a new experience, as most had not had the opportunity to openly express their ideas in the conventional classroom environment.

Problem solving

As outlined above the teaching strategy aimed to promote understanding of the primary force concept, and required an application of forces, net force and force diagrams in the solution of dynamics problems. However, a consideration of Episode Three indicates that (initially at least) the thinking of all three students was dominated by an intuitive view of the phenomena. For the accelerating cart, the responses from each student provided evidence for an incomplete understanding of the net force concept, and included a force to "explain" the orientation of the pendulum from the vertical. Students appear to have focussed their explanations on the most dominant characteristic in the situation, the orientation of the pendulum away from the vertical, in preference to applying the primary force concept. Thus the problem solving approach of students is dependent to a large extent on the context of the problem rather than the basic principles of physics to be applied. A discussion of qualitative problems in a wide range of contexts may help to overcome this difficulty.

CONCLUSIONS

The single most important feature of the three Episodes considered above is that students are constructivist: given the opportunity, physics students will make their own sense of any physical situation provided, which may or may not be congruent with the scientific explanation. The adoption of a teaching strategy focussed on POE experiments, qualitative problems and classroom discussion was supportive of their constructivist tendencies, and was beneficial in alerting them to alternative conceptions and the promotion of learning. This research supports the view that in addition to the emphasis on alternative conceptions, constructivist teaching strategies should also aim to provide a wide range of problem contexts, encourage correct use of terminology and promote a learning environment supportive of student views.

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"THE SUN IS SLEEPING NOW": EARLY LEARNING ABOUT LIGHT AND SHADOWS

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ABSTRACT

To keep intuitive knowledge fluid for an extended time, we wish to encourage young children to examine continuously those intuitive explanations for natural phenomena which later become hard wired, highly resistant to development or change. To assist this we designed a learning package which integrated three extensively researched educational strategies (cooperative learning, informal inquiry and familiar context) for children to explore their notions about the topic *light*. Children in a kindergarten class were encouraged to share their ideas about shadows and shadow formation with peers, as they took part in explorations of shadow formation inside and outside their classroom. Whole class discussions, small group conversations and final conversations between researcher and small groups provide insights into social and individual construction of knowledge, young children's abilities to be scientific and the social construction of gender.

INTRODUCTION

Among many reasons advanced for unsuccessful learning of science has been the failure of teachers to recognise and take account of children's intuitive ideas about physical and biological phenomena (Osborne & Freyberg, 1985). Where children's ideas are recognised and specific teaching strategies have been adopted to effect conceptual change, claims of success have been mixed (e.g. Cosgrove, Osborne & Carr, 1983; Ramadas & Driver, 1989, cited in Osborne & Black, 1993). A major point we wish to explore is the possibility of obviating the problems of later conceptual change by finding ways of keeping children's intuitive knowledge fluid and flexible.

BACKGROUND TO THE STUDY

Ausubel (1968) foreshadowed findings on difficulties of teaching for conceptual change when he asserted:

> The unlearning of preconceptions might well prove to be the most determinative single factor in the acquisition and retention of subject-matter knowledge ... [These] preconceptions are amazingly tenacious and resistant to extinction because
>
> * of the influence of such factors as primacy and frequency;
> * they are typically anchored to highly stable, related and antecedent preconceptions of a more inclusive nature;
> * they are inherently more stable, ...and,
> * resistance to the acceptance of new ideas contrary to prevailing ideas seems to be characteristic of human learning. (p. 336)

We therefore set out to study what happens when we raise children's awareness of their implicit assumptions about the physical world, thus keeping their views plastic and examined, subject to modification through developmental processes and increasing experiences. This process of encouraging young children to scrutinise continuously their own knowledge itself mirrors scientific habits and may, if introduced early, become inserted in their developing schemata (Thagard, 1988) as a kind of default strategy. That is, before accepting perceptions uncritically, young children can be encouraged to question tenaciously the validity of these perceptions by seeking confirmatory evidence.

It is known that learning languages occurs at so called "critical periods" where learning is most rapid. Later, when these critical periods have passed, learning becomes more difficult (Bunge & Ardila, 1987). We suggest there may be similar critical periods in which children learn rapidly, intuitively, and even nonchalantly about physical phenomena in their immediate environment. Our research begins a series of longitudinal studies which seek to identify suitable times to raise children's awareness of their intuitive ideas about certain phenomena before they become hard-wired.

As there is little research about how young children learn science and technology in early childhood classes in Australian schools (Fleer, 1990), our preliminary work involves us in describing in detail ways in which young children develop their ideas in our chosen educational settings. In this paper we describe the learning of some kindergarten children about shadows (a subset of our topic, light). We also inquire into their social construction of knowledge (Resnick, 1991) as we attempt to follow changes in conceptual understanding which may occur during our lessons and how our three part learning model comprised of cooperative groups, informal inquiry and familiar context assists in this process.

LIGHT AND SHADOWS

The primary reason for choosing light is a sensory one. Children should, we contend, be helped to understand how they gather information (and later, how they process it) through their senses. Another major criterion is that of inclusiveness (Suggett, 1987): the topic light was reasonably highly ranked for both boys and girls when primary-aged children were asked to express preferences for learning in science topics (Qualter, 1993; Smail, 1987). Although there is no information about how young Australian children (aged 5 to 9) think about shadows and shadow formation, other information is available for our use in devising probes to assist us to take a fine-grained approach in monitoring children's learning and progression in ideas (Piaget, 1930/1970; Guesne, 1985; Feher & Rice, 1988; Osborne & Black, 1993).

Our research differs from the above, in that we do not set out to conduct interviews with individual children, (although we may converse with individuals during class time), nor do we have a deliberate agenda of effecting conceptual change. In our quest to keep ideas about shadow formation plastic, we raise some ideas in whole class settings, frame conversational probes to small groups and encourage small groups to engage in discussion of ideas.

LEARNING MODEL

Our inclusive teaching/learning model is designed to surround children with a variety of enjoyable, intellectual experiences which include their worlds of home, play and school. The model embraces cooperative learning, informal inquiry and familiar context. We wish to use inclusive strategies to make early learning of physical science personal and enjoyable for girls and boys and to help develop children's social skills: these are two of our implicit assumptions about purposes of science education in early childhood. Cooperative learning meets these criteria (Johnson, Johnson & Holubec, 1990). Our choice of informal inquiry as part of our model stems from our desire to link cognition and affect. When children plan, predict and control their learning, they not only enjoy themselves but are motivated to learn and thus may advance cognitively (Maehr, Midgly & Urdan, 1992).

BEST COPY AVAILABLE

Many motivational activities, regarded by children as play, can be arranged so that children's learning takes place through natural explorations, discussions and investigations of shadows. This is our context - a judiciously arranged variety of educational settings which will encourage children to converse about phenomena and events in ways which may reveal their underlying assumptions to themselves and others.

In our endeavour to raise children's awareness of their implicit views about physical phenomena, we identify another of our underlying assumptions about the purpose of science education in early childhood -that young children are capable of, and enjoy, intellectual discussion about and investigation of their physical world. Our model may be a suitable vehicle for inquiry into this assumption.

THE STUDY

The school in which this research was carried out is situated in a middle class area of Sydney with the majority of its children of Australian or European background. In this paper we report upon data from a Kindergarten class; (N= 28; average age 5) which Gilda taught over a period of five weeks, with one or two half hour sessions each week. It was a directly expressed preference of the class teacher that Gilda teach the class, but the teacher assisted the children as needed, was generous with advice, and helped organise the children into groups. In brief, we planned to:

- observe children in their classroom with their regular teacher, prior to beginning the unit, so that the children and teacher had time to establish a friendly relationship with Gilda,
- teach the unit, using a sensitive mixture of educational settings (with which the children were familiar) and which blended with our learning model,
- record observations by audio taping and videotaping group interactions,
- converse with some children after the unit was completed,
- review observations with the class teacher and other researchers,
- converse with some children again in 12 months time (not reported upon here).

Seven cooperative groups (each of four children) were established and the children familiarised with the video and audio equipment during a short introductory stage of two half hour lessons. This was followed by the shadows stage of four half hour lessons. The research concluded with conversational interviews with children in the same groups as in the teaching stages. Interviews lasted about 15 minutes on average for each group.

To assist children to develop ways of interacting within their small group and to arouse children's awareness of each other's prior ideas, Gilda moved one group to the front of the class at the beginning of the shadows stage. She modelled how the leader might ask others, in turn, about shadows; what the leader might do if a team member could not think of an answer and what the leader could do if the leader had run out of ideas. The group carried out this activity as the class listened and watched.

For the final group interviews, the same materials which had been used in class were present on a small table and in every case, children were keen to play with them again. Light from a window to the side of the table fell on the table and shadows of the object formed from this natural source, were also used in eliciting responses from the children.

FINDINGS AND INTERPRETATIONS

We present our findings through excerpts from conversations and our interpretations of them and attempt to trace development in social and individual construction of knowledge about light and shadows as it occurred in small groups and in the whole class group. Our sequenced presentation has the advantage of embedding some answers to our questions in the contexts in which the answers arose.

Conversing about shadows in small groups

Children were keen to air their ideas. Most children followed modelled instructions about how to include everyone's contribution to share their knowledge of shadows. This is illustrated in the following excerpt of an early conversation between four five year olds, prior to beginning practical activities.

Tim	What do you know about shadows Leanne?
Leanne	They follow us.
Tim	What do you know about shadows Michelle?
Michelle	They don't sleep.
Tim	Yeh that's right. What do you know about shadows David?
David	Well they do what we do.
Tim	I know all about shadows. They were um in the sunny time and you're standing in the sun and when you walk, they follow you. Isn't that right?

Though most groups concentrated on the form and behaviour of shadows, this group was unusual in that the children explicitly mentioned the sun and there was little concentration on the human form of shadows. As the conversation proceeded, we noticed that our stylised model for group interactions was altered as differences in views became apparent and children's consciousness of their ideas was raised.

Tim	What do you know about shadows, Michelle?
Michelle	They copy you.
Tim	Yeh. What do you know else about shadows, David?
David	They go to sleep with us.
Tim	No they don't go to sleep.
Leanne	They're there when you go to sleep.
David	Of course, you can't see them at night.

Tim's disagreement with David's reified view of a shadow being able to go to sleep demonstrated that he recognised at this time, that he had a distinctly different view of what constitutes a shadow. Leanne's addition indicated that she had followed this exchange and that she also categorised her view as different to that of David. Now Tim continues the modelled structure, as it is his turn to make a comment. He changes the discussion to observations about shadows of trees.

Tim	I know about shadows - that they move from the trees.
David	And they climb up the trees when we climb up the trees.
Tim	No they don't.
Leanne	You can see a shadow on the ground, can't you Tim.
David	You can.

Tim's view could have been that the movement of the leaves of the trees is responsible for the movement of the shadows of those leaves on the ground. His ambiguous statement apparently stimulated David to think of himself and his shadow climbing a tree, but Tim rejected this - he was either thinking of the shadow of a tree on the ground or, consistent with his rejection of the shadow as an active sleeper, he rejected the concept of a shadow as an active climber. Leanne's contribution indicated that she was again listening and thinking about the exchange. Her comment may indicate that she assumed shadows are usually seen on the ground, thus supporting Tim's contention.

Reporting about shadows

Reporters informed the class what their group knew about shadows. For example:

Jenny They're invisible. They do what we do. They have no eyes. They have no noses.
Leanne They're invisible. They copy us.

Reporters offered a fraction of the information that was shared in their group. This is exemplified by Leanne, who offered one piece of information that was mentioned in group discussion ("They copy us") and one piece that was not mentioned in her group, but which was mentioned by another child. ("They're invisible"). It is possible that contrasting views (possibility of shadows on or off the ground) made her knowledge tentative, in the process of construction, not yet ready to articulate. Young children's answers in this setting may conceal their knowledge, even when it has recently been uttered in discussion. (Leanne did not state any of her personal contributions made in small group discussion.) It is also probable that young reporters cannot remember or understand all the information about shadows stated by other group members and some may be inhibited by shyness.

Many answers contrasted aspects of shadows with aspects of human beings. Some researchers state that animistic responses of children do not necessarily indicate that children are unable to differentiate between animate and inanimate objects (Inagaki & Hatano, 1987), but whether these responses were indications of beliefs in animate shadows or not, many children willingly joined in talking about these kinds of properties of shadows. It is also probable that as our inside context was set for discussion about this 'thing' called a shadow, young children would predictably concentrate on its form, rather than on the role of light in forming and seeing shadows.

Informal inquiry outside

Action outside was purposeful. Children walked around, examining their shadows, doing sudden twirls to look for their shadows again and in the case of some boys, repeatedly kicking their shadows against the wall, clutching their toes as they rebounded from the wall with cries of seemingly joyful anguish. Six boys joined in this activity; two girls watched for a very short time and then moved away. This reminded us of examples given by Kelly (1987) in secondary science classes in which boys constructed science as masculine by creating links from the science activity to their strength.

As some children moved into the sun, they spontaneously expressed ideas to Gilda that they had not previously raised in small group discussion: "Sometimes they don't go in shade." "You can't see them in the shade."

There was great excitement towards the end of the time outside, when the sun went behind a cloud. Some children rushed up to Gilda to tell her that their shadows had disappeared. One little girl, Maria, explained seriously: "The sun is sleeping now!" Maria linked the presence of the sun with shadow formation.

Gilda But what has the sun got to do with the shadows?
Maria It shines on us and then there's the shadow.

Whole class discussion

Gilda suggested it would be interesting to share something new that they discovered about shadows outside, and after contributions such as "They follow you and copy you." "They can't come off the ground." "They can move.", children moved outside to check the validity of reported observations.

The capacity of children of this age to maintain a continuity of purpose and thought is shown in this interaction between Leanne and a parent helper.

Parent	Leanne, can you remember what you're checking?
Leanne	Yes, checking if they climb up the wall.

The claim she was planning to check was raised in their group discussion from the lesson held three days earlier, where David said shadows climbed trees with him and Leanne remarked that shadows are found on the ground.

Children in another group considered, then investigated whether their shadows could be seen in the sun and in the shade and began to develop significant theories about the position of the sun and shadow formation.

Denis	Look, it's behind you.
Ken	You're facing into the sun.
Colin	Oh it's behind me.
Ken	Yes, but you have to be facing into the bright sun.
Colin	Hey it's beside me.

In this exchange, Ken inferred and then re-affirmed that if the shadow was behind them, the sun must have been in front of them. The conversation resumed with a further addition to the group's knowledge construction, as Denis added a powerful insight, which seemed lost on Colin.

Denis	Colin, if you're facing into the sun, if you, you're going to, it's 'cos the sun moves round, your shadow moves round.
Colin	No, it goes where you're going.
Denis	Yeh, but when you go, it's moving round as well.

We do not know what led Denis to relate the movement of the shadow to the movement of the sun, but claim that the cooperative group/informal inquiry setting, in which intellectual conversation was being encouraged, played a part in his sharing this knowledge with others in his group.

Knowledge passing from small group to individual to class

Some of the children's contributions in the following class lesson can be linked back to group conversations outside. Michelle, in the role of group reporter provides an interesting example. Although Michelle was not recorded as making any verbal contribution to the conversation outside between her group and the parent helper, she rather shyly informed the class, "When you try to climb, they climb." We claim her reporting of this particular item of knowledge is far from accidental. It is consistent with Leanne's answer to the earlier parental inquiry where she told the parent that she was "checking if they climb up the wall" and can be traced back to the small disputation about whether shadows climb, which occurred in her group's original discussion. Gilda discussed further with the class a view expressed by one child that his shadow was still present in the shade, but was invisible. She asked the class to think of themselves in their beds at night, to pretend that there was no light in their room and to state their opinion as to whether they would still have a shadow. Opinions in the class were divided roughly equally. Children stated a variety of reasons for their opinions, with Nathan saying:

> Yes. If you jump in the shade, you can't see it but it's really there. Leaves have got little spaces under – um – between them – they can't fill the whole thing up and then you can just see your head on your body and when you're in your room you can't see any of you because you're asleep and sometimes you can't get to sleep and you can't see your shadow and you can't even see your shadow.

Here is evidence of analogical reasoning of a high order. Nathan reasoned that if he could see part of his shadow in between leaves of a tree, then the part of his shadow that he could not see, was really there. He pushed this reasoning on, to explain that in complete darkness, his shadow would be present for the same reason. On the one hand he could not see it if he were asleep, and on the other, he could not see it if he were awake, in total darkness.

Using torches in small groups

This activity was greeted with excitement. Children mostly worked as individuals in their group, as they shone their torches at the small attractive toys and ornaments. There was very little talking (apart from one group) but there were a wealth of actions and non verbal interactions. Reporters had a lot more to say this time.

> Nathan When we put, pulled the torches up the shadows got much littler and when we put it down it got much bigger and we didn't shine the torches into eyes but some people did. And the bigger, and when you put the torch up, the um, circle got bigger and when you put it down it got much littler.
> Maria When we put the hippopotamus down we slowly pulled the torch up and shined it on the hippopotamus and we pushed it up and then I pulled it up a little bit and the hippopotamus shadow turned into an elephant.
> Ainsley Adrian and me put our hands on the torch and it made our hands red. I moved the torch around and the shadow moved.

Here are clearly articulated spontaneous investigations and reports of findings, some of which beautifully exemplify scientific practice. Knowledge shared here was rich in variety, compared with the earlier sets of reporters' comments.

Final conversations: one week after the last lesson

Many additional ideas were expressed: Some were in response to researcher probes, some stemmed from the shadow already visible on the table, before torches were switched on; some came from direct experimentation with the torches; some were spontaneous. Most of the children seemed to be trigger model users (Feher & Rice, 1988), with a strong sense of the shadow belonging to the object and with light acting either as an active agent (pushing the shadow out) or a passive agent (needing to be present for the shadow to be seen).

Some children discovered to their surprise that the shadow on the table did not move to the other side of the animal when the animal was turned through 180°. A few predicted the outcome correctly.

During these conversations, children chatted about home and school. Jody volunteered: "Last night I had two shadows because there were two lights". Here is an example of a five year old child engaging in significant scientific theory building, using ideas and materials from our educational settings with observations made at home in a seamless interweaving. Furthermore, this causal link between the presence of light and shadow is a necessary step towards a full understanding of shadow formation.

SIGNIFICANCE OF FINDINGS

We believe that our educational settings have promoted intellectual discussion, providing critical opportunities for young children to uncover and discuss their ideas about physical phenomena. In these settings, they articulated tacit knowledge, (sometimes in response to specific probes), thereby in our opinion, making this knowledge accessible and helping to keep it plastic. It appears that much of what is discussed in such settings is not and might never be revealed for a class teacher's inspection. Our observations of children behaving casually and even seemingly off task in groups, particularly in outside settings, belie the serious conversations occurring there.

In small group conversation with peers, we have seen that children are confident to express their implicit ideas, seemingly unperturbed even if these ideas differ from their peers. This situation may contrast with other settings where adults may inadvertently break conversational rules (Siegal, 1991), confusing children and causing them to lose confidence in their answers.

To be sure of allowing very young children every chance to air their assumptions, many different settings seem called for. In early small group and class discussion, very few children mentioned the sun or other light sources in connection with what they knew about shadows, but a brief sojourn outside the classroom, immediately triggered spontaneous comments linking the sun's movement behind a cloud with the disappearance of their shadows. Similarly, many children observed shadows in their home environment, but for most, it was not until the final interview setting that children began spontaneously to report observations made at home and to theorise about them.

In addition to our settings themselves acting as probes, some conversational openings provided insights into children's ideas about light as well as shadows. Two such probes which were effective were: To encourage children to consider whether their shadow would still be present in their pitch dark room at night; and to predict whether the shadow of a small animal would change sides when the animal was twisted through 180°.

Our analysis of the reporters' comments revealed the children's deepening and broadening insights over the course of the study. At first they were pre-occupied with the shape and form of their own shadows, speaking about them in phrases or simple sentences consisting of a few words. Later, they articulated theories concerning possible roles of the sun and other light sources in shadow formation. By the end of the study children expressed in long, complex sentences the diversity of their findings after experimentation with torches. We suggest that this burgeoning of knowledge construction reflects children's abilities to operate successfully within our learning model.

We also contend from our research that pathways can be traced from knowledge which is first shared socially in the form of uncertain and contradictory assertions in a small group to significant individual learning. In this paper we described one of many such examples, where Michelle's group performed a critical test to distinguish between two conflicting claims and Michelle constructed personal knowledge about shadows, reporting "When you try to climb, they climb." Here we can speculate too that she has learned about the value and method of seeking evidence for claims -a fundamental tenet of scientific inquiry.

Our settings were chosen with inclusion in mind, inclusion which related to choice of topic, learning model, choice of materials and choices of activities. Nevertheless a small group of boys violently "attacked" their shadows on a brick wall and others played spontaneous games of "stamping on its head" and "kill the shadow". None of the girls engaged in this type of activity. We feel there are pedagogical implications here. If these or other semi-violent actions were to become widespread during science lessons in kindergarten, the fragile gender neutrality of science in these settings could be threatened, as boys re-interpret the script, making it a masculine one.

CONCLUSION

It seems that raising children's awareness of implicit assumptions in a context which stimulates thinking, nurtures and encourages the thinking process both directly and indirectly. It may be appropriate to begin the process of raising children's awareness of their views of shadow formation in kindergarten. The progression of ideas and the ways in which some children still had new ideas to offer in the final interviews seems to validate our learning model as a legitimate way of teaching and learning science.

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RESPONSE TO THE DISCIPLINE REVIEW OF TEACHER EDUCATION IN MATHEMATICS AND SCIENCE

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ABSTRACT

This paper relates to a study commissioned by the Department of Employment, Education and Training to evaluate the impact of the Discipline Review of Teacher Education in Mathematics and Science. The major data-gathering strategies employed in that study have been to visit every higher education institution in Australia involved in teacher education to interview relevant staff and to seek information by mail from other bodies to whom recommendations of the Review were addressed. This paper reports a supplementary activity, the analysis of citations of the Report of the Discipline Review in the journal of the Australasian Science Education Research Association, Research in Science Education. This research reveals that there has been relatively little critical analysis of the Review, somewhat surprising in the light of its significance for science teacher education. Further the citations in the journal suggest that the Review Report has struck a responsive chord with those involved in the science education of primary school teachers. Its impact on secondary teacher education would appear to be less significant. This difference is explored in the context of professional education.

INTRODUCTION

As part of a process of review of higher education programs the Australian Government commissioned a Discipline Review of Teacher Education in Mathematics and Science whose findings were published in a 3 volume report (Department of Employment, Education and Training, 1989). One of the recommendations of the Review was that the Department "commission a study, in 1993, to report on the implementation of the recommendations of this Review". (Vol.1, p. 205)

The Department acted on this recommendation during 1992 calling for proposals to conduct a study which would investigate the impact of the Review. The authors of this paper were contracted to carry out the study which is expected to be published during 1993.

The authors appointed project staff and invited interstate colleagues to form a team to enable visits to be made to all institutions in Australia involved in teacher education programs leading to awards. During these visits members of the project team interviewed people with responsibilities for areas of study which were the focus of recommendations in the Review Report. The interviews were designed to elicit information on the extent to which current practice in the institution was consistent with the recommendations of the Review, and the interviewee's perceptions of both the impact and processes of the Review.

Further data were gathered by mail from other organisations, for example state ministries of education, to whom recommendations were directed.

Another source of information on the impact of the Discipline Review is the literature. This paper presents an analysis of the references to the Review in Research in Science Education (RISE), it being assumed that this will be the major source of insights into the response to the Review of Australian science education specialists in higher education.

REFERENCES TO THE REVIEW

The number of articles in RISE in which reference is made to the Review is 1 in 1989, 4 in 1990, 10 in 1991, and 6 in 1992. Since the Report was published in 1989 it is not surprising that there is only one citation in that year. The response in 1990-1992 suggests that the Review has been noted by a significant number of science teacher educators.

What is of interest is the focus of articles in which the Report is cited. Of the 16 citations in 1991 and 1992, 13 were concerned with what the Review had to say about primary school science and the education of teachers to work in that area. This is a matter which will be taken up later in the paper.

Two articles were written by people involved in the Review process itself. Fensham and West (1990) described and commented upon the procedures employed in the Review. Fensham et al (1991) reported analyses of some of the data which had been gathered during the Review. The first of these papers is significant in that the authors placed before the science education research community the rationale for the way the Review Panel had defined and measured quality in teacher education. The concluding paragraph acknowledges that the Review processes are contentious:

> others will judge the success of the Review's approach. The panel remains convinced of the superiority of their approach over the alternative... (Fensham & West, 1990, p. 92)

The second of these papers provided further background to the Review, setting out some of the assumptions which underpinned the procedures adopted by the Review Panel. In that paper the authors described the way in which the Panel had chosen to think about the knowledge important to the teacher of science.

> The panel thus saw a science teacher as a person (a) who has acquired, and knows how to acquire a body of scientific knowledge, (b) who understands that a curriculum for science is drawn up from a number of sources including as its major source, the content knowledge of the disciplines of science, and (c) who has acquired a range of pedagogical strategies that relate to the teaching of science as it has been represented in the curriculum. (Fensham et al., 1991, p. 81)

It is interesting to note that there is no critical analysis of the assumptions of the Review Panel about these matters published in RISE, despite the fact that their position was explicitly drawn to the attention of the science education community through these papers, presented at the annual conference of the Australasian Science Education Research Association and later published in RISE.

This is not to say that there has been no critical comment of the Review published in RISE. In the context of a paper outlining the development of a "gender-sensitive" model of teacher education, Bearlin (1990) offered a substantial commentary of the Review with respect to its representation of the issue of gender in science education. She proposed three models of exemplary practice with different assumptions about changing the attitude of women primary and early childhood teachers to science, and differing treatment of gender issues, and used these as the background for comment on the Review.

In the first of the models, the subject-centred model, the problem is seen as women having inadequate scientific knowledge and the solution is therefore the provision of such knowledge. Gender is not seen as relevant.

In the second, the learner-centred model, the problem is seen as women perceiving science to be a fixed body of expert knowledge, or as due to gender-role socialization. From this viewpoint the solution lies in focussing on the learning of young children and involving women in practically oriented activities designed to change their view of science. Gender, if seen as relevant, is an equity issue added on to the curriculum.

The third, the knowledge and person-centred model, which sees gender as a central issue, assumes a transformation of the whole teacher education curriculum. Both knowledge and persons are seen as socially constructed and hence gendered. It is concerned with changes to the attitude of women both to science and to themselves through their participation in gender-sensitive and gender-inclusive learning experiences and reflection on these experiences.

Whilst commending the Review for the emphasis placed on gender issues, Bearlin was critical of the perspective portrayed both in the body of the Report and in the commissioned paper (Parker & Rennie, 1989) included in the Report of the Review. She argued that the writers of the Report, whilst espousing a social constructivist view of knowledge, do not see it as gendered. The document thus has an "add-on" perspective to gender. Neither the teaching-learning process nor scientific knowledge are seen as gendered and needing to be reconstructed. Her analysis of the Parker and Rennie paper led Bearlin to conclude that, while the contribution of the paper to the Review is of value, it does not go far enough. She stressed the need to "look more closely at the way in which boys and girls, and men and women, are active in their gender construction and the way in which science and science education are involved in this". (Bearlin, 1990, p. 29)

Matthews (1990) was critical of the failure of the Review to recommend that history and philosophy of science be seen as a component of an ideal programme of teacher education. He argued that "science teachers who know something of the history and philosophy of their subject can enliven their classroom presentations". (p. 227) He further contended that "a competent grasp of the STS materials and the Gender Issues that the Review is rightly concerned with, requires some knowledge of the history of science, and this in turn some knowledge of the philosophy of science". (Matthews, 1990, p. 228)

THE REVIEW AND PRIMARY TEACHER EDUCATION

As indicated above, the minimal amount of critical commentary on the assumptions of the Review is one of the issues which has emerged from an analysis of the papers published by science educators in RISE. The second issue, which was referred to earlier in the paper, is that the vast majority of citations are in articles about science in primary schooling rather than those about secondary education. This is perhaps all the more surprising when it is noted that in both of the papers prepared by the people actively engaged in the Review (Fensham & West, 1990; Fensham et al., 1991) the examples chosen to illustrate the points being made are concerned with secondary teacher education.

There were two papers published in RISE between 1989 and 1992 specifically dealing with secondary teacher education which cited the Discipline Review. Aubusson et al. (1991) reported data about the perceived professional devel-opment needs of a sample of secondary science teachers in Sydney. The authors drew attention to the fact that, in contrast to the recommendations of the Review, the teachers sampled expressed a preference for traditional modes of inservice education. Forgasz (1991) reported a study in which she investigated whether their own gender, or the gender of the students they were teaching, influenced the assessment done by student teachers in a secondary Diploma of Education program. She cited the work of the Discipline Review as a source of information on which she had drawn.

By contrast there were 14 papers about primary school science in the same period which cited the Discipline Review. Further the major focus of these papers was the importance and nature of discipline studies in science in primary teacher education programs.

One of the papers dealing with primary education came from the present authors (Symington & Mackay, 1991). That paper reported some of the data arising from an empirical study into the reaction of a sample of primary teacher educators to the parts of the Report of the Discipline Review dealing with early childhood and primary teacher education. The paper reported data relevant to the issue of discipline knowledge in science of students in primary teacher education programs. The authors concluded that "Whilst not disputing the place of science discipline knowledge in teacher education courses, some teacher educators appear to be unconvinced that the suggestions regarding testing and time allocation to such studies (made in the Report of the Review) are the appropriate ways to approach the issue". (p. 312)

Another paper dealing with the issue of discipline knowledge and one which establishes that the Discipline Review has had an impact on some of those responsible for primary teacher education is that of Jane, Martin and Tytler (1991).

> Preservice primary teachers also lack confidence in teaching science as outlined in the Discipline Review of Teacher Education in Mathematics and Science (1989). The review recommends an increase in the amount of science taken by primary teacher trainees, particularly in the area of background science knowledge and in identification of "gaps that can be remedied by suitable bridging studies". This recommendation has been implemented at Victoria College by introducing into the Bachelor of Teaching course a unit called Professional Readiness Study - Understanding Science". (p. 188)

Carr and Symington (1991) also addressed the issue of discipline knowledge. Their paper accepted the importance of a focus in pre-service primary teacher education on the understanding of the student teachers of science knowledge and proposed a way in which the matter could be addressed.

> "Science discipline knowledge" should be taken to include the nature of science itself. Further the analysis of floating and sinking [the topic explored in the paper] suggests that such an understanding can be derived through a program which explores concepts and processes related to primary school curricula. Such an approach seems more appropriate to the interests and the needs of those preparing to be primary teachers... It is to be hoped that responses to the recommendations of the Discipline Review will reflect the ideas presented in this paper. (p. 46)

As indicated earlier there are a further 12 papers related to primary school science which cite the Discipline Review. In general the Review is not central to the research being reported. Rather it is used as a point of reference. Most of these studies are, however, about primary teachers' lack of confidence in science and science teaching.

DISCUSSION

The difference between primary and secondary teacher education in the responses of this group of science educators to the recommendations of the Discipline Review requires consideration. What are the reasons for the recommendations related to primary teacher education producing so much more reaction than those related to secondary teacher education? The present authors believe that difference is best understood in terms of a consideration of the nature of professional education, in particular for the profession of teaching.

The knowledge which teachers are expected to acquire during their pre-service education is frequently divided into two domains viz. discipline knowledge and professional knowledge. The Discipline Review, as was indicated earlier, established three domains: discipline knowledge, pedagogical knowledge and curriculum knowledge. The Report of the Discipline Review emphasised the importance of each of the domains. For example, there are recommendations which suggest that in primary teacher education the mathematics and science discipline knowledge should be explicitly taught and assessed. At the same time the Panel identified linkages between the domains and did not suggest that they needed to be taught separately.

> It is proposed that the equivalent of 50 per cent of the 72 hours be devoted to specific science content in both physical and biological topics. The content needs to be explicit and assessed, with students expected to achieve a minimum level of competence. It is expected that the remaining 50 per cent will be given to curriculum and pedagogy for early childhood and primary school children.
>
> The Review Panel is not prescriptive about whether the explicit science content is part of specialised units or incorporated into science curriculum units. (Department of Employment, Education & Training, 1989, Vol 1, p. 39).

In primary teacher education in most institutions discipline knowledge and curriculum knowledge have been taught together. In general, it is one group of people who have responsibility for both the discipline and the curriculum knowledge and it is representatives of this group of people who have made the relatively numerous citations of the Review. Their papers generally reflect this interest in the total development of the student; in their understanding of, and attitudes to, discipline, pedogogical and curriculum knowledge. For example, Skamp(1989) reports data on the general science knowledge and attitudes towards science and science teaching amongst preservice primary teachers. The recommendations of the Discipline Review which deal with each of the these domains are of critical importance to the everyday working life of this group of people and it is not surprising that they have reacted with interest to the recommendations of the Review.

By contrast in most secondary teacher education programs the discipline studies and the pedogogical and curriculum studies are handled quite separately and usually by different groups of people. In most institutions the discipline studies are handled in non-professional faculties where the staff have relatively little interest in relationships between discipline and professional studies. The participants in the Australasian Science Education Research Association who work in secondary teacher education are in general those responsible for professional studies and with little influence on what happens in the discipline studies. This limits their interest in the range of recommendations of the Review. They see recommendations about the nature and content of discipline studies as outside their sphere of influence and so have been less stimulated by the Review Report.

CONCLUSION

The analysis undertaken and reported here would suggest that there was relatively little critical discussion amongst science teacher educators of the assumptions made by the Review Panel. Further the recommendations of the Review appear to have raised more interest at the primary than at the secondary level.

This difference between the responses of primary and secondary teacher educators has been discussed in this paper in terms of the difference in the professional preparation at these two levels. The Discipline Review argued for increased attention to science discipline studies in primary teacher education programs. Although the Review Panel did not press for discipline studies and professional studies to be separated, in some universities the primary teacher education program is being changed to more closely resemble the secondary program, with discipline studies being separated and taught outside the education faculty.

This paper cannot address all of the issues involved in such a development. However, the data presented do raise a question to be considered in such a context: are there virtues in the science discipline and professional studies being handled by the one group of people, those with a professional interest in the outcomes of the total program? The data presented in this paper indicates that those people currently charged with this dual responsibility have a high level of interest in the total development of primary teachers with respect to science. Relevant university authorities would do well to take this factor into account when planning the future of teacher education programs.

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THE EVOLUTION OF AN APPROACH FOR USING ANALOGIES IN TEACHING AND LEARNING SCIENCE

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ABSTRACT

An important contribution to effective teaching and learning can be made by teachers' understanding of the central topics in each subject area and knowing how to transform their content knowledge into knowledge for teaching. One aspect of this knowledge is the use of analogies which can effectively communicate concepts to students of particular backgrounds and prerequisite knowledge. Indeed, analogies are considered to be an important component in the repertoire of effective teachers. However, research about teachers' use of analogies in science lessons provides little guidance about the optimum approaches that may be taken by preservice teachers, novice teachers, experienced teachers or reluctant analogy users. This paper describes the evolution of an approach for using analogies in science teaching that addresses both findings from the research literature and recognises the needs of practising teachers.

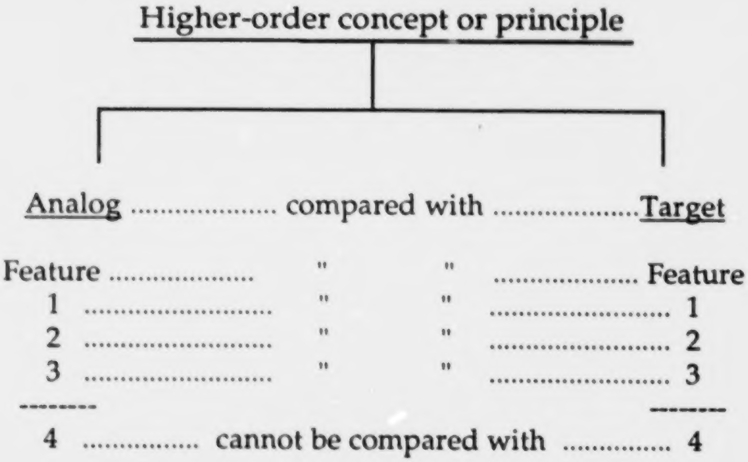
INTRODUCTION

Recent research has shown that a significant factor enabling teachers to create conditions where effective learning occurs is related to teachers' subject matter understanding. Of special importance is the teachers' content-specific pedagogical knowledge which includes understanding the central topics in each subject area as it is generally taught to students of a particular year level and being able to transform the content knowledge into knowledge for teaching (Shulman, 1986). One aspect of this content-specific pedagogical knowledge is the use of analogies which can effectively communicate concepts to students of particular backgrounds and prerequisite knowledge. Since students often lack the background knowledge to learn difficult and unfamiliar topics encountered in biology, chemistry, and physics, one effective way to deal with this problem is for the teacher to provide a bridge between the unfamiliar concept and the knowledge which students possess. This bridge can be an analogy which allows new material, especially abstract concepts, to be more easily assimilated with the students' prior knowledge enabling them to develop an understanding of the concept. In this paper, relevant issues related to the use of analogies in science teaching firstly are reviewed, and secondly important findings from a research program designed to help science teachers use analogies more effectively in their teaching are described.

ISSUES RELATED TO THE USE OF ANALOGIES IN SCIENCE TEACHING

A useful working definition of an analogy is that "it is a correspondence in some respects between concepts, principles, or formulas otherwise dissimilar. More precisely, it is a mapping between similar features of those concepts, principles, and formulas" (Glynn, Britton, Semrud-Clikeman, & Muth, 1989, p. 383). Simply stated, an analogy is a process of identifying similarities between two concepts. One concept, which is familiar, is referred to as the *analog* and the other concept, which is unfamiliar, is called the *target*. Usually the target relates to the scientific concept.

In using an analogy in science teaching, teachers should select a student world analog to assist in the explanation of the content specific target (or topic). The analog and target share attributes that allow for a relationship to be identified and contribute to the knowledge base of teaching. However, there are features of the analog which are unlike the target and these can cause impaired learning if incorrectly matched. A useful representation of how an analogy works is shown in Fig. 1.


Higher-order concept or principle
Analog .... compared with ....Target
Feature .... " " .... Feature
1 .... " " 1
2 .... " " 2
3 .... " " 3

----
4 .... cannot be compared with 4

Fig. 1. Representation of how an analogy works (Adapted from Glynn, 1991)

In the history of science, analogies have been tools of discovery. For example, Johannes Kepler developed his concepts of planetary motion from the workings of a clock (Bronowski, 1973) and Huygens used water wave motion to understand light phenomena (Duit, 1991). A key question for science education researchers to investigate is whether secondary students can economically and repeatedly employ these same analogical reasoning skills to understand a new phenomenon. Cosgrove (1991) answered such a question when he described how 14 year old boys discovered a valid model for an electric current using their own analogies. A similar question was asked by Wong (1993) when teacher education students created their own analogies to explain three air pressure phenomena.

An example of one analogy that has been used in chemistry textbooks (Lewis & Slade, 1981, p.1) to help explain aspects of the region of influence of an electron is that of a rotating propeller. In this analogy, the target concept is an understanding of the characteristics of an electron's region of influence. The analog is a description, or diagram, of a rapidly rotating plane propeller. There are several shared attributes that are readily compared. When the propeller is rapidly rotating, it is not possible to state exactly where the blade is at any given instant and yet, if a person was to attempt to insert a stick into the general area, they would find that the propeller's properties are applied throughout the whole region. Similarly, the electron, due to its rapid motion and wavelike properties, exerts its presence throughout a large orbital region without being specifically present at any exact location at any given instant. This comparison of shared attributes is known as *mapping* and involves a deliberate categorisation of those attributes that are shared between the analog and the target. It is also true that there are attributes of both the rotating propeller system and the area of electron influence that are not shared. For example, the propeller is fixed in its orbit of rotation, whereas the electron is mobile within a probabilistic three-dimensional orbital. It must be considered that the analog and the target will have many attributes that are not shared. Good mapping should also give an indication as to where this occurs so that unshared analog attributes are not ascribed to the target domain.

The use of analogies does not always produce the intended effects, however, especially when teachers discover that students take the analogy too far and are unable to separate it from the content being learned. Some students only remember the analogy and not the content under study, while others focus upon extraneous aspects of the analogy to form spurious conclusions relating to the target content. Uncritical use of analogies may generate alternative conceptions (Champagne, Gunstone, & Klopfer, 1985), and this is especially so when unshared attributes are treated as valid (Cosgrove & Osborne, 1985), or where the learners are unfamiliar with the analogy (Gentner & Gentner, 1983).

Research has shown that the effectiveness of analogical instruction can be improved by training students in analogical reasoning (Friedel, Gabel & Samuels, 1990). Indeed, several authors nominate analogies as candidates for generating dissonance between children's science and scientists' science (Cosgrove & Osborne, 1985) and as being important elements in the learner's conceptual ecology (Strike & Posner, 1985).

Different types of analogies

The research literature identifies different types of analogies, including verbal, pictorial, personal, bridging and multiple analogies (Duit, 1991). The first three of these analogies are the most useful for teaching. With verbal analogies presented by the teacher, the student is usually left to elicit the necessary comparisons and conclusions about the target from the description of the analog. Pictorial analogies may be presented by the teacher to highlight the desired attributes of a selected analog. This visualisation reduces the likelihood that students are not sufficiently familiar with the analog. In practice, most pictorial analogies are accompanied by some verbal explanation and should be referred to as pictorial-verbal analogies.

Personal analogies assist students by relating abstract scientific concepts to students' real world considerations such as people, money, food, and relationships. Students can be physically involved in a personal analogy by, for example, being asked to walk around the classroom in such a manner that their direction of travel is analogous to the motion of electrons through a wire or ionic migration through a solution during electrolysis. Alternatively, the students may only be involved at a mental level. Research suggests that personal analogies cause better learning of concepts and that this learning approach is enjoyable; however, personal analogies can cause students to give intuitive feelings to inanimate objects and concepts.

The advantages of analogies in teaching

Analogies are believed to help student learning by providing visualisation of abstract concepts, by helping compare similarities of the students' real world with the new concepts, and by increasing students' motivation (Duit, 1991). The presence of pictures is an aid to understanding. Similarly, the presentation of a concrete analog facilitates access to the abstract concept by pointing to the similarities between objects or events in the students' world and the phenomenon under discussion. Analogies can be motivational in that, as the teacher uses ideas from the students' real world experience, a sense of intrinsic interest is generated. However, it should be noted that little has been determined from empirical studies about the actual learning processes that are associated with analogy-assisted instruction since most of the studies have only measured the students' recall of learned materials. It also is not well known if analogies really do assist students to attain a level of conceptual understanding or whether students only use the analogy as an effective algorithmic method to obtain the correct answer. Nevertheless, whichever of these possibilities is correct, there are benefits to using analogies in teaching science.

From a teaching perspective, the use of analogies can enhance students' understanding since they open new perspectives. In addition, when teachers use analogies this creates an increased awareness on the part of the teacher to take students' prior conceptions into consideration in teaching. By becoming more aware of students' conceptions, differences between student ideas and those of the teacher become more evident.

The constraints of analogies

Despite the advantages and usefulness of analogies as previously outlined, the use of this teaching tool can cause incorrect or impaired learning related to the analog - target relationship. For example, the analog used in the explanation may be unfamiliar to the learner. Analogies may be useful in assisting students who primarily function at the concrete operational level (Gabel & Sherwood, 1980) but if these students lack visual imagery, analogical reasoning, or correlational reasoning, then the use of analogies may be limited, despite the finding that they may be useful. Students already functioning at a formal operational level may have an adequate understanding of the target and the inclusion of an analogy might add unnecessary information. For these reasons, some teachers choose not to use analogies at all and thereby avoid these problems while, at the same time, forsake the advantages of analogy use.

A third constraint of analogy use is concerned with the attribute(s) shared between analog and target. No analog shares all its attributes with the target or by definition it would become an example. The attributes not shared are often a cause of misunderstanding for learners who attempt to transfer them from the analog to the target.

Another related constraint occurs when students attempt attribute transfer in an inappropriate manner. Rather than using the analog attributes as a guide for drawing conclusions concerning the target, the students occasionally incorporate parts, or all, of the analog structure into the target content. One of the results of this incorrect transfer is that when students are questioned concerning the nature of the target content, they will answer with direct reference to analog attributes.

Teachers' use of analogies without inservice education

From our research (Treagust, Duit, Joslin, Lindauer, 1992; Thiele & Treagust, 1991) and research published elsewhere (Dagher & Cossman, 1992), it is apparent that analogies are not used by science teachers as often as might be expected. This is in spite of the existence of useful analogies in textbooks used in science classrooms (Thiele & Treagust, 1993; Thiele & Venville, 1993). In addition, research suggests that when analogies are used in class they are frequently not presented in a manner which enhances their effectiveness. It seems most likely that the vast majority of science teachers have no formal training in the use of analogies and hence it is not surprising that so little use is made of them.

THE NEED FOR ANALOGICAL INSTRUCTION INFORMED BY RESEARCH

If analogies are to be used effectively by science teachers, then a carefully planned pedagogy is called for, within which the analogies used are relevant to as many students as possible. In attempting to address this problem, a number of models or teaching approaches for reliable and valid use of analogies in classroom instruction have been produced. Four such models are Brown and Clement's (1989) Bridging Analogies, Dupin and Johsua's (1989) Analogy Teaching Model, Glynn's (1991) Teaching-With-Analogy model, and Zeitoun's (1984) General Model of Analogy Teaching (GMAT). While not a specific teaching model for analogy use, Cosgrove and Osborne's (1985) four phase conceptual change model highlights the value of analogies by suggesting their inclusion in the challenge stage of teaching.

Given the lack of opportunities for teachers to learn about analogy use, one proposal is to offer inservice activities which deal with the issues presented in this paper. Inservice may take the form of learning how to implement a teaching model using analogies. The model described by Glynn (1991), which was derived from an analysis of science textbooks, has six steps:

1. Introduce the target concept to be learned.
2. Cue the students' memory of the analogous situation.
3. Identify the relevant features of the target concept and the analog.
4. Map out the similarities between the target concept and the analog.
5. Draw conclusions about the target concept.
6. Indicate where the analogy breaks down.

Using the rotating propeller analogy for electron influence around a nucleus, Thiele and Treagust (1991) describe how the six steps can be implemented in teaching:

> 1. Due to the rapid motion and wavelike properties of electrons, it is not possible to suggest that they are in any particular location at any given instant in time.
> 2. Remember that when a plane's propeller is rotating at top speed, you can't see exactly where the blades are, you just see a blurred circle.
> 3. When the blade is rotating, it seems to be covering the whole circular area at the same time — there doesn't appear to be anywhere the blade is not evident and yet it is not in any exact place.
> 4. An electron revolves rapidly around the nucleus of an atom. We cannot say that it is at a particular place at any time - only that we know it is in a general region.
> 5. We can conclude that the influence of the electron will be spread over the whole region through which it moves.
> 6. We should realise that the propeller is fixed in its rotation - it rotates the same way, at the same speed, and at exactly the same radius for every two dimensional rotation. This does not happen with the electrons which are not fixed in their three dimensional orbits.

Although at first this procedure may seem difficult, it is probably no more so than learning any multi-step skill such as driving a car for example. In the latter case, at the outset the learner has a large number of things to remember - gear in neutral, hand brake on, look in rear vision mirror, look ahead, switch on ignition, depress clutch, engage gear, release clutch, look in mirror again, hand brake off, drive away. Soon these single events become as one and the whole procedure is done without attention to the separate events. The same situation occurs with any approach for learning how to teach science with analogies.

Research conducted by Treagust et al. (1992) showed that science teachers did not use analogies often in their regular teaching, though we observed two teachers who used enriched analogies and included them in their lessons in a manner similar to the approach taken by Glynn (1991). Within the discussion of the concept of half-life in radioactive decay in a Year 12 Physics lesson, the teacher drew an analogy between the target concept and probability controlled games such as a lottery or dice throwing (Step 1). In this analogy the teacher explained that every nucleus has the same probability to be changed (to a nucleus of another element) in much the same way as every lottery player has the same chance of selecting the correct number (Step 2). Not only was this particular analogy a good example of the working definition of a relation between parts of structures of two domains (the radioactive nuclear decay process and the selection of number in a lottery draw), it also was taught in an effective manner (Steps 3 and 4). The teacher discussed the limitations of this analogy with the students, namely that in nuclear decay, time is involved as chance within a certain period of time but in a lottery it is not (Steps 6 and 5). The teacher also briefly mentioned the aspect of luck. In further elaborating this analogy, the teacher employed the tossing coin analogy in order to explain that after two half-lives, not all nuclei have changed but there are still 25% left. He further explained some common misunderstandings of this point.

In the second analogy used in this lesson, the teacher drew analogies between three different types of fields, namely the electric, the magnetic and the gravitational fields, with analogies between the electric and the gravitational fields being given much attention. An interesting switch between the fields was observed in that the teacher changed the roles of analog and target several times, that is, he used the electric field to work out features of the gravitational field and vice versa (Steps 1, 2, 3 and 4). During this discussion, the teacher described some of the limitations of the field lines in that they "are not real things, there is a field also between the field lines" (Step 6) and suggestions were sought from students (Step 5).

This dual use of analogies is of great importance in helping students understand complex concepts since whenever an analogy is used, the target is developed and so is the analog because it may be viewed now from a new perspective, namely the perspective of the target.

Development and evaluation of analogical teaching

The above three cases of effective analogy use appear to be a natural approach for introducing complex and non-observable concepts. It should be noted that those teachers who used analogies effectively reversed steps 5 and 6 in Glynn's model. Building on this earlier work, during the past three years colleagues and myself have been working with more science teachers to observe their use of analogies in science lessons and to develop, implement and evaluate systematic teaching approaches whereby analogies can be used more effectively by attending to the issues described in this paper.

In his research with teachers who received inservice instruction about the teaching-with-analogies model, with steps 5 and 6 reversed, Harrison (1992) observed that when inserviced teachers presented analogies systematically, the resultant student understanding was compatible with scientists' views. Harrison and Treagust (1993) reported in detail the teaching of an analogy for explaining light bending as it passes from one transparent medium to another. Although this phenomenon is familiar to students, at least in the science laboratory, its explanation is fraught with conceptual difficulties. With this problem in mind the teacher analogically demonstrated refraction by rolling a pair of Lego wheels coated with paint obliquely from a smooth surface (cardboard) onto a rough surface (carpet). When the wheels rolled from the cardboard onto the carpet so that the wheels crossed the interface simultaneously, no bending occurred. However, when the wheels crossed the interface obliquely at about 30 degrees, the wheels changed direction in a manner comparable to the refraction of a light beam passing obliquely from air to glass. Following the lesson, Harrison interviewed all students and the teacher, and administered analogical mapping charts to students. The analysis of these data indicated overtly how the teacher had utilised all the six stages of the Glynn model for analogical instruction and that this teaching approach was effective in enabling students to better describe the phenomenon of refraction of light.

Three months after the lessons on light, Treagust, Harrison and Venville (1993) interviewed all students from the class taught with the wheels analogy, and also a parallel class in the same school taught by the same teacher, which did not receive analogical instruction. The results from the interviews-about-instances protocol on different aspects of refraction illustrated that the students taught with an analogy were able to explain not-previously-seen phenomena and to have understood the crucial aspects of refraction far better than those students who had not been taught refraction using an analogy. Treagust et al. (1993) hypothesised that the analogical instruction appeared to provide useful avenues for engendering student conceptual change.

As might be anticipated from competent teachers with whom we are working, they interpreted the Glynn teaching-with-analogies model in their own way and further modified the teaching approach for incorporating analogies into their science teaching. The resultant teachers' use of Glynn's model and our own analyses of that teaching has enabled us to develop a simpler and what at this stage appears to be a more effective and efficient three-phase model of analogy teaching.

In teaching with analogies, teachers initially considered the concept to be taught (was it difficult, unfamiliar or abstract?), whether or not the students already knew something about the target concept, and whether or not the students were familiar with the analog. This *Focus* on analogical instruction took place both before and within the early part of the lesson, depending upon the circumstances. During the class presentation of the analogy, teachers paid careful attention to the likes and unlikes of the analog and the target, discussing both features of the analog and target and drawing similarities between them as well as ways the analog and target are not alike. We have called this the *Action* phase of analogical teaching. Following the presentation of the analogy, teachers reflect on the clarity and usefulness of the analog and consider ways in which the analog may be improved. This *Reflection* phase may take place within the lesson itself or after the lesson as later preparation occurs. We have observed that in practice these phases are not distinct but run into one another.

FOCUS		
	CONCEPT	Is it difficult, unfamiliar or abstract?
	STUDENTS	What ideas do the students already have about the concept?
	ANALOG	Is it something your students are familiar with?
ACTION		
	LIKES	Discuss the features of the analog and the science concept. Draw similarities between them.
	UNLIKES	Discuss where the analog is unlike the science concept.
REFLECTION		
	OUTCOMES	Was the analogy clear and useful, or confusing?
	IMPROVEMENTS	Refocus as above in light of outcomes.

Fig. 2. The three aspects of the FAR guide for teaching and learning with analogies

To assist teachers in analogical instruction based on our research, we have produced a guide for teaching and learning science with analogies. In doing so, we use the three phases of the teaching approach, *Focus*, *Action* and *Reflection*, to form the acronym FAR (see Figure 2). The purpose of the FAR Guide is to help teachers maximise the benefits and minimise the constraints of analogies when they arise in classroom discourse or in textbooks. The guide has come about as a result of many hours observing and interviewing teachers and students and has been designed, as much as possible, to reflect the skilled way in which an exemplary, practised teacher uses analogies in their teaching of science. The phases of the FAR Guide have become second nature to those teachers who have been familiarised with them and they have been usefully applied to the teaching of analogies. Most of all, preliminary research with the FAR guide indicates that teachers and their students benefit from, and enjoy analogies when teaching and learning science. Our research group now is engaged in further research in order to better understand how students learn by analogies.

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TEACHER AND STUDENT USAGE OF SCIENCE TEXTBOOKS

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ABSTRACT

This study examines the differences between teachers' and students' perceptions of textbook usage in the science classroom. Four categories of use were identified: teacher directed student activities; teaching/studying guidance; as a source of information for the user and as preparation for assessment. The results of the study show that differences do occur between teachers and students with respect to their perceptions of the extent to which textbooks are used in the classroom and the purposes for which they are used, namely as a teaching/studying guide and as preparation for assessment. The findings of the study should be important to all those who use, write and publish high school science textbooks.

TEXTBOOKS IN SCIENCE EDUCATION

Over the last three decades, numerous studies have examined many different aspects of textbooks and their usage in science classrooms. Textbooks have been variously described as the 'tools of the teacher's trade' and as a principal means of spreading knowledge (Kamm & Taylor, 1966); as being central to the teaching of science; as dictating the science curriculum which students experienced and of acting as the primary source of knowledge for most students (Gottfried & Kyle, 1992). Ade-Rioder (1989) shows that students spend a great deal of time and energy reading and digesting the material in their textbooks and that teachers depend on textbooks for information. There have also been other studies which have shown that textbook usage in class has been, and is as high as 90% of available classtime (Muther, 1985; Woodward, 1988; Laws, Horsley, Young & Downey, 1990; Shymansky, Yore & Good, 1991). Yager (1983) has even asserted that the selection of a textbook is one of a science teacher's most important instructional decisions.

Notwithstanding this high status and usage in teaching, textbook authors and teachers' reliance upon textbooks have been criticised. Authors have been accused of treating scientific concepts superficially (Ruis, 1988); making extreme vocabulary demands which often exceed that required for foreign language mastery (Yager, 1983); not utilising accepted theories of teaching (Mann, 1981); presenting the development of science as errorless and linear (Kuhn, 1970) and acting as the prime determiners of what students must do and learn (Yager, 1983). Teachers have been criticised for promoting teaching as the transmission of facts from textbooks (Wellington, 1989); for hiding behind the text's terminology to mask their own lack of understanding of scientific concepts (Yager, 1983); for being inflexible in using textbooks (Davey, 1988) and for using textbooks to give students a false impression of the nature of science (Chiappetta, Sethna & Fillman, 1991).

Textbooks have also been examined for their level of conceptual difficulty (Vachon & Haney, 1983), their effects on student comprehension (Hare, Rabinowitz & Schieble, 1989) and as a source of student misconceptions about science (Cho, Kahle & Nordland, 1985). However, amongst this plethora of research there appears to be little which compares the perceptions which teachers and students have about the way in which textbooks are used. Studies conducted by Laws, Horsley, Young and Downey (1990) and Cook and Tulip (1992), imply that teachers and students may differ in their perceptions about textbook usage in science classes. The former study found that students value a textbook primarily for security as it provides the information which needs to be learned for examinations and the latter study found that teachers value a textbook primarily for its emphasis on student cognition. This apparent disparity of values between teachers, as directors of textbook usage, and students as users, is a cause for some concern. It implies that both parties involved have perceived that the resource is being used for entirely different purposes. This must surely create an inefficient usage of the resource which the literature shows is a very important component of science teaching. This concern has given rise to the research question for this study. 'Do students perceive the usage of textbooks in a science classroom differently from teachers?'

METHOD

To compare teachers' and students' perceptions of textbook usage it was necessary to place realistic limits on the dimensions of comparison. Four major areas of usage were determined from the literature (Spiegel & Wright, 1984; Chiappetta et al., 1991; Gottfried & Kyle, 1992; Yore, 1991; Roth & Anderson, 1988; Shymansky et al., 1991; Yager, 1983). Textbooks are used to provide: teacher directed student activities; teaching/studying guidance; a source of information for the user; and ideas for assessment.

A questionnaire of ten items representing these four major areas of usage was developed. The ten items were chosen by a panel as being representative of the four areas of usage because they depicted common classroom occurences in terms which students, as well as teachers, would be able to recognise and associate with. For ease of reference the items were labelled using the letters A to J in the order they appeared in the questionnaire. For 'teacher directed student activities', the items were: to set students' homework (J); for student activities (E); for class reading (I). For 'teaching/studying guidance', the items were - to determine depth of topic (C); to determine sequence of topic (B). For 'a source of information for the user', the items were: for examples (D); for explanations (A); for teacher demonstrations (F). For 'ideas for assessment', the items were: for examination questions (G); for projects (H). These items were not intended to canvass all possible areas of textbook usage. Rather, they were chosen because of their commonality of terminology between teachers and students and the belief that the response on these items would be sufficient to indicate whether a difference in perceptions of usage existed between teachers and students.

Two equivalent forms of the same questionnaire were prepared, one worded appropriately for students and the other for teachers. For each item teachers and students were asked to record their perceived level of usage of the textbook and any anecdotal comments they wished to make. A Likert type scale of "All of the time", "Most of the time", "Some of the time", "Seldom" and Almost never" (scored 5/4/3/2/1) was defined on both questionnaires in terms of decreasing percentages of times for which the textbook was perceived to be used.

PROCEDURE

The teacher version of the questionnaire was distributed to 250 secondary high schools in Queensland as a component of a larger study (Cook & Tulip, 1992). Questionnaires were completed and returned by 390 teachers, representing responses from 130 schools. The sample of students used in the survey was made up of 444 students from years 9 and 10 from the teacher schools surveyed. The classes of students represented a cross section of science classes throughout Queensland. The sample was an extension of that used in the study by Tulip and Cook (1991).

RESULTS AND TREATMENT OF DATA

Median scores were calculated as data was both ordinal and not normal in distribution (Isaac & Michael, 1985). The semi-interquartile range was calculated for each median to give a measure of the variability of the median score and the significance of the difference between

TABLE 1
COMPARATIVE ORDER OF TEXTBOOK USAGE BY ITEMS RANKED ACCORDING TO TEACHERS' PERCEPTION OF USAGE

Item Code	Item	Teacher			Student			Significance of Difference between Medians
		Median (N = 390)	Semi-inter-quartile Range	Rank Order	Median (N = 444)	Semi-inter-quartile Range	Rank Order	
J^1	to set students' homework	4.14	0.55	1	4.53	0.71	1	< 0.01
E^1	for student activities	3.99	0.48	2	4.14	0.84	2	< 0.01
C^2	to determine 'depth' of topic	3.56	0.74	3	3.33	0.83	8	< 0.05
D^3	for examples	3.43	0.63	4	3.69	0.75	7	< 0.01
B^2	to determine 'sequence' of topics	3.39	0.85	5	3.27	0.75	9	Not Significant
A^3	for explanations	3.30	0.77	6	3.91	0.62	4	< 0.01
F^3	for teacher demonstrations	3.10	0.85	7	3.73	0.87	5	< 0.01
I^1	for class reading	3.01	0.82	8	3.94	0.85	3	< 0.01
H^4	for projects	2.07	0.77	9	2.78	1.05	10	< 0.01
G^4	for examination questions	1.65	0.73	10	3.70	0.86	6	< 0.01

Areas of major textbook usage are shown as superscripts on Item Code:

1. Teacher directed student activities 2. Teaching/studying guidance 3. Source of information 4. Ideas for assessment

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medians was found using the Median Test, which is in effect a chi square test (Isaac & Michael, 1985).

The perceived level of usage of each item by teachers and students was determined by the median score for that item. Based on decreasing median scores the items were ranked from 1 to 10. Table 1 shows a comparison of median scores, semi-interquartile ranges and the rank orders of both teachers' and students' perceptions of textbook usage in the classroom.

The patterns of perceived texbook usage in terms of the major areas of usage and the rank orders defined by both teachers' and students' responses are summarised in Fig. 1.

	Responses							
Rank Order	Teacher directed student activities		Teaching/Studying guide		Source of information		Ideas for assessment	
	Teacher	Student	Teacher	Student	Teacher	Student	Teacher	Student
1	J	J						
2	E	E						
3		I	C					
4					D	A		
5			B			F		
6					A			G
7					F	D		
8	I			C				
9				B			H	
10							G	H

Fig. 1 Teachers' and students' patterns of perceived textbook usage

DISCUSSION

The extent of the differences between students' and teachers' perceptions of the usage of textbooks in science classes is evident from Table 1. For eight out of the ten items on the questionnaire the students' median score is greater than the teachers' median score and the difference between them is statistically significant ($p<0.01$). Only on one item is the teachers' median significantly greater than the students' median ($p<0.05$) and there is one item on the questionnaire on which no significant difference occurs between medians. It appears that teachers believe that they use textbooks in the classroom to a lesser extent than students believe is the case.

However, not only is there a difference in the perceived levels of usage, there is also a difference in the patterns of perceived usage (see Fig. 1). There is limited agreement about the importance of three major areas of textbook usage, 'Teacher directed student activities', 'Source of information', and 'Ideas for assessment', but there are also some clear differences within these areas and strong disagreement in the area of using textbooks as a 'Teaching/studying guide'.

The reasons for these differences are open to debate. In the teaching/studying guide area, it could be argued that students would tend to rank the items more lowly because they have little or no control over the sequence and depth of topics in their courses of study and therefore would not use the textbook for these purposes. By contrast, however, the high ratings given to items B and C by the teachers, indicate that Queensland teachers still rely significantly upon textbooks for guidance on what to teach, when to teach it and to what depth it should be taught even though modern educational theory and preservice teaching courses often indicate that this is poor pedagogical practice (Roth & Anderson, 1988). It appears that with respect to this issue, pragmatism carries more weight with teachers than theory.

In the other three areas of textbook usage, the rankings of items I and G displayed the greatest differences between teachers' and students' perceptions. As shown in Figure 1, the students ranked item I highly, suggesting that they believe teacher-directed student reading is widely used in the classrooms. By contrast teachers indicated that the practice is not particularly frequent. Similarly, the rankings obtained for item G show students use the textbook as a source of examination questions far more frequently than teachers. Furthermore, students substantiated their usage of the textbook in this manner by comments on the questionnaire asking for more answers to problems to help in their study for examinations.

These results give rise to further speculation about the importance of theoretical concepts in teaching practice when it is noted that both items I and G have been strongly criticised in pre-service teacher courses (Roth & Anderson, 1988). In contrast to the results obtained for items B and C, in this case the teachers appear to practise what theory suggests. Could it be that some theories are more in vogue than others or could it be that there is a difference between what teachers (or students) do in the classroom and what they report they do?

CONCLUSION

The differences between teachers' and students' perceptions of textbook usage in the science classroom which this study has reported, raise some issues which should be of concern to teachers and textbook authors. The data suggest that students perceive textbooks to be a very important part of their science education. Teachers, however, appear to downplay their usage in the classroom. This incongruence could have deleterious ramifications. Chiappetta et al. (1991) and Laws et al. (1990) have described students' narrow perceptions of science as that information which is in the science textbook and the results of this project seem to support these findings. If this image of science is to change, authors and publishers will need to introduce to textbooks mechanisms which encourage students to perceive textbook usage in the science classroom differently from that currently employed. This view is supported by Ormiston-Smith (1993) when she states that "textbooks should be written as an argument for the plausibility, fruitfulness and intelligibility of their content" and Morris and Stewart-Dore (1987) when they advocate techniques by which students can gain meaning from textbooks rather than use them as objects of memorisation. Of course, such mechanisms will be useless teachers adopt and support them.

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DEVELOPMENTAL ASPECTS OF PRIMARY SCHOOL CHILDREN'S CONSTRUCTION OF EXPLANATIONS OF AIR PRESSURE: THE NATURE OF CONCEPTUAL CHANGE

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ABSTRACT

A considerable amount of work has focussed on children's 'alternative conceptions' in science and their resistance to change. This study looks at the language in which children frame explanations in science, and the consistency of these explanations across contexts. Schoolchildren of age from 5 to 13 experimented in small groups with a range of activities illustrative of 'air pressure'. An analysis of transcripts of their discussions and of several written probes indicates a developmental factor in childrens preference for both explanatory forms and conceptions, in the types of links they made and in the consistency of their explanations across contexts. The analysis gives new insights into the nature of conceptual change.

INTRODUCTION

Much work has been done in recent years in the description and theoretical consideration of the many 'alternative conceptions' that children hold in relation to natural phenomena. Conceptions that children bring to the classroom are found to be not only rich and varied, but are surprisingly resistant to change through instruction (Champagne, Gunstone & Klopfer, 1982), and over time (Engel Clough, Driver & Wood-Robinson, 1987). This stability contrasts with findings that children can adopt a range of often contradictory conceptions to explain different phenomena. Engel Clough and Driver (1986), in a study of the stability of alternative conceptions across contexts, found the evidence equivocal. In a more recent study Bloom (1990/1992) has shown children's thinking to be extremely fluid, progressing via a rich selection of episodic knowledge, metaphors, interpretive frameworks and attitudes. The extent to which children hold and use consistent 'alternative conceptions' over a range of contexts has implications for the extent to which we view conceptual change as 'radical restructuring' (Vosniadou & Brewer, 1987; Carey, 1985), and how we conceptualize the conditions that will favour such conceptual change.

White (1987) calls for more research on the formation and change of young children's conceptions, and for the development of a representation of cognitive structure that captures its fluidity. Most of the alternative conceptions research has sought to probe children's conceptions at fixed points in time. There is a need for a greater focus on the dynamics of children's ideas; the explanatory strategies they use, and the genesis of these strategies over the early school years.

The research was undertaken with the following questions in mind:

- What strategies do children use in constructing explanations of natural phenomena?
- Do children use explanatory conceptions in a consistent way, across contexts that scientists recognize as illustrating the same principles?
- How do these strategies, conceptions and consistency of application vary over the primary school years?

METHOD

A preliminary study involved the analysis of transcripts of a class of year 2/3 children's discussions of a range of activities focussing on the concept of 'air pressure'. The main finding of interest here is that children, rather than showing evidence of a coherent 'alternative framework', seemed to operate with a cluster of 'interpretive conceptions' representing multiple, sometimes contradictory perspectives that included analogies, metaphors and mental models. These findings have been reported elsewhere (Tytler, 1992).

The preliminary study also uncovered differences in approach between year 2/3 and year 7 children. To explore these developmental issues the study has been extended to run with children over a range of year levels – Prep (Age 5/6), Years 3/4, 5/6, 7 and adult – and to include several written probes. Each of the schools used had a predominantly middle-class clientele, and in the case of the Australian primary classes, the children were accustomed to working in science in small groups. In a sense, then, the results can be expected to represent optimum performance levels for children at each age. The year 7C class was from a local Melbourne secondary school, while the 7M class was, like the 2/3 class that was used in the preliminary study, from a school in Warwickshire, UK, where primary schools extend to Year 7. The adults were primary school teachers taking a science unit as part of a post-initial qualification.

In session 1, after an introductory discussion to focus attention on the topic of 'Air', the class was organized into groups of 3 or 4 children, who undertook a sequence of tasks intended to reinforce the idea that air has a tangible presence. Each task involved an element of surprise (The 'dry tissue', for instance, involved a tissue in an upside down glass plunged into a bucket of water, and emerging still dry). Groups were asked to work towards an explanation of each task, that they all agreed on. The discussions in each of the groups was recorded, and analyzed, and the children were asked for a written explanation of each of the tasks. In the case of the prep children, 'conferencing' was used to record their verbal explanations. In session 2, the same procedure was followed for three different sets of four tasks intended to illustrate the principle of differential air pressure. The groups were then reconstituted so that each child was responsible for presenting their tasks within the new group, which then came to an agreed explanation of each of the twelve tasks. The group discussions in both phases were recorded. A 'Link' probe was given, in which children were asked to identify and describe links between the tasks. For the Year 7 children and adults, these activities were telescoped into one session.

The 12 tasks used in Session 2 were arranged as three groups (Red, Yellow & Green) of four. These included:

R1 'The tricky straw': A straw is pricked in a number of places with a pin, so that it cannot be successfully used to drink through.

R2 'The upturned glass': A glass full of water with a piece of paper across the rim is upturned. The water does not spill out.

Y1 'The magic finger': A can full of water has three holes punched in the bottom and one in the top. Flow of water through the bottom holes is controlled by closing and opening the top hole with a finger.

Y4 'Cup and saucer': A full beaker of water with a saucer on the top is turned upside down. The water does not come out, unless the water round the bottom of the saucer is sucked with a straw.

G1 'The sticky dart': A rubber suction cap is pressed onto a tile. It is difficult to remove.

G4 'Linked syringes': Two syringes are joined by a plastic tube. Pushing one in causes the other to be pushed out. Pulling has the opposite effect.

The role of the researcher and teachers in each of these sessions was to circulate amongst the groups, clarifying tasks, encouraging discussion and focussing the children's attention on the questions.

ANALYSIS

The language of childrens explanations

The SOLO taxonomy (Biggs & Collis, 1982; Collis & Biggs, 1991), which offers a model for characterizing levels of sophistication of children's developing conceptions, and hence explanations, was used as the basis for an analysis of the childrens written explanations. The principles on which explanations were assigned to the various levels, within the 'concrete-symbolic' mode of functioning, mainly hinge around the sophistication of causal notions.

1. Prestructural explanations, involving non-acceptance of the problem. There is no sense of a causal relationship, and 'explanations' essentially amount to statements of the outcome of the task e.g., 'The card stuck on', 'It was hard to suck'.

2. Unistructural explanations, in which one reason only is given, without any mediating description of a sequence of causally linked events. This level of explanation indicates 'premature closure', and often a jumping to conclusions without sufficient attention to the details of the implied explanation e.g., 'It squashes the air and that makes it stick', 'Our lungs are sucking the drink up'.

3. Multistructural explanations, in which a causal chain is given in the explanation, linking two ideas in a sequence. There is no attempt, however, to raise the explanation to the level of a generalization e.g., 'She sucks up the air and the water comes up after it', 'Water came out of the bottom of the container because air coming through the top allowed water to escape'.

4. Relational explanations, which extend relevant points to a general principle, or interrelationship between factors. The relations here would refer to general principles of the action of air on water, or that of the competition for space e.g., 'When we blew through the straw we made the air pressure very high because there was nowhere for it to escape from. When we stopped blowing and took our mouth away, it was able to escape so the water spurted out the straw to get the air pressure back to normal'.

SOLO levels of children's written explanations

Using the schema described above, the children's explanations were categorized for the 'dry tissue' and 'sinking boat' tasks (B3 and B4), and the four tasks (R, Y or G series) done by the group in the first part of session 2. The explanations of the preps were dictated to adults using the conferencing procedure. The results are shown below. The numbers are presented as percentages of the total number of n responses at each year level.

TABLE 1
SOLO LEVELS OF WRITTEN EXPLANATIONS

Year level SOLO level	Prep n=170	2/3M n=31	3/4L n=100	5/6T n=139	7C n=125	7M n=37	Adult n=72
1. Prestructural	75	45	39	18	19	8	1
2. Unistructural	21	52	52	52	53	65	3
3. Multistructural	4	3	8	28	26	25	82
4. Relational	0	0	1	2	2	3	13

The table shows a marked developmental trend in level of explanation. This involves rather more than simply an increase in fluency of explanation; in 'getting better' at explaining. The taxonomy describes qualitative shifts in style of explanation. The older children, and especially the adults, are successfully using explanatory paradigms that the younger children are not attempting to use at all. The results support the contention (Biggs & Collis, 1991, Jones, Collis & Watson, 1993) that young children operate predominantly in the sensorimotor (associated with performance of activities) and ikonic (involving intuitive knowledge perceived as images) modes, and that these are used to support concrete-symbolic thinking in the earlier SOLO levels. Notions of 'trapping' or 'squashing', or 'sucking' are essentially ikonic, but could be seen as precursors to more abstract ideas of pressure and competition for space. The notion of cycles within the taxonomy, with higher order generalizations giving rise to further multistructural and relational levels (Levins & Pegg, 1993, Levins, 1992) has not been explored in this study, but if the study was extended into secondary school where children had been recently exposed to ideas of atmospheric pressure, and gas theory, one could well see that such a layered analysis may become necessary.

One of the problems in interpreting such a taxonomy is that the written explanation will be determined by a number of factors:

1 Knowledge/understanding of science principles and ideas that impinge on the explanation, such as the nature of air, or force, or pressure.

2 Appreciation of explanatory forms in science (ie. the closeness of causal connections that constitute an acceptable explanation).
3 Judgment as to what is the appropriate level of explanation in the context.

4 Contextual factors such as time available, level of interest, writing skills etc.

The distinction between factors 1 and 2 is a difficult one to make, and at a deeper level is bound up with the relationship between language and thought. An appreciation of notions like 'force' and 'pressure' would presuppose, for instance, familiarity with causal connections, and would make further causal connections possible. It is not clear, from this context, how much the trend identified above represents a developmental change in 'domain-general' factors such as notions of causality, or in 'domain-specific' knowledge such as of air and its behaviour (Carey, 1985). The trend in sophistication of explanatory form, identified here, is accompanied by increasing sophistication in conceptions, involving notions of force, pressure, and the competition for space.

Socio-cultural factors would also come into play. Children, as they participate in the schooling process, become increasingly familiar with acceptable forms of explanation. It could be that exposure with age to an increasing presumption of having to justify one's ideas leads to greater facility with and acceptance of explanatory principles. This occurs, for a child, both in the context of interaction with adults, and also with peers. It was noticeable, for instance, that prep. children did not interact conceptually with each other to any extent. The notion of workshopping explanations to come up with a group consensus appeared alien to them. The adults, on the other hand, workshopped ideas seriously and did not reach agreement until a range of ideas had been explored.

Several studies have explored 'misconceptions' held by primary teachers. This group of adults also displayed 'misconceptions' about the behaviour of air, but they had a very different approach to generating new conceptions compared to primary school children, operating at a much higher level of linking principles and reflecting on implications, with a much greater knowledge base. The 'alternative conceptions' younger children hold should not be seen in isolation from understandings about and experience with the nature of science explanations, and of the way scientists make sense of the world.

The 'link' probe : perceived similarities between tasks

The 'link' probe consisted of a series of ikons, each representing a task. Children were asked to join with a line, or branching lines, tasks in which 'something similar is happening'. They were asked to write a brief reason for each link. Again, a conferencing procedure was used with the preps.

There was a difference in the number of links children identified, and in the style of the reasoning they used to justify these links. The justifications were categorized using a four-point scale:

Level A:	Based on physical similarity of equipment. ('They both have straws')
Level B:	Based on the nature of personal action. ('We used a finger to block a hole in these')
Level C:	Based on situational similarity with respect to equipment or matter. ('Air is trapped inside', 'they stick', 'water comes out')
Level D:	Based on the identification of an underlying principle. ('Air pushes', 'air is used to lift water', 'hard to pull because air wasnt getting in')

This scale was used to analyze the children's responses and these were expressed as a percentage of the total recorded responses. In Table 2, n represents the number of children, and L the number of links described. Quite clearly, none of the preps are looking for links based on principle, while this is becoming a significant aspect of the links made by the 5/6/7s. Conversely, by 5/6 and particularly 7, children do not see physical similarity or human action as being an appropriate basis for linking the tasks. These older children would have

- access to knowledge schemata (properties of air, pressure) that younger children do not, which enables them to see relationships.

- a greater awareness of fruitful ways to look at phenomena, and of the limited usefulness of A and B levels of operating

- an ability and preference for operating at an abstract, 'relational' level

It seems likely that all these factors would be operating interdependently.

TABLE 2
TYPE OF LINK PERCEIVED BETWEEN CONTEXTS

Year level Type of link	Prep.T n=27 L=73	3/4L n=21 L=100	5/6T n=25 L=78	7C n=25 L=78	Adult n=15 L=42
A. Physical similarity	59	5	0	0	0
B. Human action	16	8	0	0	0
C. Situational similarity	25	42	63	63	7
D. Underlying principle	0	45	37	37	93

The reversal of the trend with the Year 7C also occurs on other probes. It seemed clear, while the class was in progress, that it was not operating as effectively as the primary school classes. The day on which the session was run was hot and the session was squeezed into one long time slot. In addition to this, the fact that the children did not have the teacher for subjects other than science, and it was not in a 'home room' setting, meant that there were constraints on the way groups operated. It also seemed clear that there were more social factors such as gender interplay and overt disinterest operating against effective reflection on the tasks than with the younger age groups. The fact that the year 7 primary school group from the UK (7M) performed more consistently with trend lines established with the younger age groups supports this contextual explanation. One could extrapolate the point to argue that the primary school environment is more supportive of children's learning. Certainly the results attest to the importance of contextual factors in determining learning outcomes, and the necessity for being sensitive to these when planning or interpreting research.

Explanatory conceptions used by children of different ages

Nine explanatory conceptions ('interpretive frameworks') were identified in the preliminary study, and these were extended and refined following analysis of children's written explanations in the current study. The following list places these conceptions in a rough order of increasing sophistication.

Pre-explanatory conceptions which are not explanations in any real sense:

1. Description of observations ('The water spurted out')
2. Human agent ('Because we blew hard')
3. Intentionality attributed to objects ('The air wanted to escape')

Intermediate conceptions which represent images and generalized statements that do not really address any real causal notion that would be scientifically acceptable:

4. Unfocussed references to 'air' ('The air made it happen') or (4A) to water as a causal agent ('The water blocked it')
5. 'Trapped' image ('The air and water were trapped in the can')
6. Movement of air ('The air couldnt circulate and so couldn't push')

Advanced conceptions which involve conceptual entities such as force or pressure, and would be acceptable in some form as explanations:

7. Action of enclosed air to exert a force ('The air in the jar forced the water out'), a (7A) suction effect ('The air under the dart sucks it onto the surface'), or (7B) a pressure reduction/creation ('By blowing we increased the pressure')
8. Action of outside air to exert force ('The air pushed against the dart')or (8A) pressure ('The pressure from the outside air held the card in place')
9. Competition for space ('The water can't get out unless air can get in to take its place')
10. Differential pressure ('The outside air presses harder than the air and water inside')

This list is more complex than, but is not inconsistent with, the 'alternative frameworks' identified by Sere (1982), Engel, Clough and Driver (1986) and Brook and Driver (1988).

By examining the written explanations for session 2 it was possible to analyze the extent to which different age levels favoured particular conceptions. While a listing of the use of individual conceptions indicated a complex interaction between tasks, groups and year levels, the more general banding of conceptions showed a clear developmental trend.

TABLE 3
CONCEPTIONS USED AT DIFFERENT AGE LEVELS

Age level Explanatory level	Prep T n = 124	3/4L n = 99	5/6T n = 136	7C n = 126	7M n = 36	Adult n = 73
Pre-explanatory	56	30	10	19	6	1
Intermediate	29	37	40	47	30	5
Advanced	11	32	45	31	64	88
Uncodable	4	1	5	3	0	5

Consistency of use of conceptions

Children's written explanations were analysed for consistency, across the five or six tasks for which they were generated. Individual children were scored according to how many times a conception was used more than once. A conception being used for three tasks, for instance, scored a consistency rating of 2, as did a case where two conceptions were each used twice. Only conceptions 5 - 10 were counted in this way, since it was felt the more primitive conceptions are not specific enough to warrant a fair comparison. The result is shown in Table 4. The numbers are small, because in many cases children (and adults) failed to generate explanations for more than four tasks.

The reason for a general trend towards greater consistency with age seems to be twofold. Clearly, since the younger children did not have access to the more advanced, generalizable conceptions, they could not display consistency of use. With age, children gain access through greater knowledge and experience to more powerful ways of looking at the way air behaves. At the same time, they are actively looking to apply their explanations more widely across contexts.

The low consistency score for all these classes illustrates the fluidity with which these interpretive conceptions are applied across contexts. While the older children are looking to

TABLE 4
CONSISTENCY WITH WHICH CONCEPTIONS ARE USED, WITH AGE

Cons. rating Yr. level	0	1	2	3	4	5	Average consistency
Prep	7	1	0	0	0	0	0.1
3/4	9	3	1	1	1	0	0.8
5/6	6	3	5	6	0	0	1.5
7C	7	7	6	1	0	0	1.0
Adult	0	0	0	2	2	2	4.0

apply their ideas more consistently, they do not do so completely. Even after mastering a generalizable conception as it applies to a subset of the tasks, children hung on to more primitive conceptions to explain others. These children do not operate with a set of beliefs ('alternative frameworks') about the behaviour of air, which they apply consistently across a range of contexts.

Discussion

This study has identified a number of dimensions on which children develop in their ability to construct explanations of scientific phenomena, over the primary school years. With age, children display:

* increased tendency to display more complex and reasoned explanatory forms.
* increased access to and use of higher order, 'generalizable' conceptions.
* increased tendency to apply conceptions consistently across contexts.
* a preference for recognition of links across contexts based on underlying principles.

These dimensions can be expected to be operate interdependently in determining children's ability to generate science understandings. Though the results reinforce the notion that children are very opportunistic in the way they use conceptions in a variety of contexts, an underlying trend has been identified in which children move from the utilitarian and opportunistic mode of 'children's science' toward the more generalizable, parsimonious notions characterizing 'scientists' science.

In terms of conceptual change, the picture that seems to emerge for individuals is one of gradual conceptual advance, with increasing use of higher order, generalizable conceptions and the gathering of an increasing number of contexts under these conceptions as they learn to use them more generally. Even after children have achieved a shift to a 'scientific' conception, they do not automatically apply it to the full range of relevant contexts, but need to learn to use it to replace earlier ideas used successfully in particular contexts. The study does not contradict the notion of conceptual change involving 'radical restructuring', but rather questions the view that change occurs as a revolution that involves the shift from an 'alternative' to a 'scientific' framework, simultaneously across a range of contexts.

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TEACHING CONTROVERSIAL ISSUES IN THE SECONDARY SCHOOL SCIENCE CLASSROOM

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ABSTRACT

A sample of fourteen secondary school biology teachers chosen from twelve schools were interviewed. The purpose was to determine their views on how controversial issues in science might be handled in the secondary school science classroom and whether the issues of surrogacy and human embryo experimentation were suitable controversial issues for discussion in schools. In general, teachers indicated that controversial issues deserve a more prominent place in the science curriculum because they have the potential to foster thinking, learning, and interest in science. The issues of surrogacy and human embryo experimentation were seen as appropriate contexts for learning, provided that teachers were well informed and sensitive to both the students and to the school environment.

INTRODUCTION

Controversial issues in science can loosely be described as those areas of science where the data itself, the collection of data, the empirical evidence or the ethics of the experiment are open to various interpretations and viewpoints. Controversial issues involve not only science but also technology, societal aspects, attitudes and values. The first problem, as noted by Wellington (1986) in relation to diverse controversial issues in the curriculum is one of deciding what is controversial and here, as in science, there are problems of definition, justification and approach. Respondents noted early in the interviews that, what might be considered controversial today might not be so tomorrow, and vice versa.

The teaching of controversial issues in science has been dealt with in the literature. Some of the literature deals with controversial issues in the context of Science, Technology and Society (Ramsey, Hungerford & Volk, 1990; Aikenhead, 1988), some with practical classroom techniques (Solomon, 1991; Brinckerhoff, 1990) and some with curriculum guidelines (Victorian Curriculum and Assessment Board, 1991). No research has been found dealing with the views of teachers (ERIC search 1982-1993).

The Victorian Curriculum and Assessment Board, in its document Victorian Certificate of Education Study Guide for Science (1991), has stated in the introduction the need for students to become aware of the important contribution that science and technology have made to the world and that new knowledge has also given rise to new problems and challenges. Such a document is of importance because it highlights the links between science, technology and society.

This article outlines a qualitative open-ended interview study with fourteen practising biology teachers from both government and private secondary schools in N.S.W. The main purpose was to ascertain how controversial issues are used currently in school science and how teachers think they ought to be used in teaching science. The interview consisted of two parts. The first dealt with questions regarding whether controversial issues might motivate students to develop an interest in science and what, if any, conditions apply. The second part of the interview endeavoured to determine whether the issues of surrogacy and human embryo experimentation could be used as controversial issues in the present N.S.W. Year 7-12 science syllabuses.

THE STUDY

The participating teachers were unaware of who else was interviewed in the study except for two interviewees at each of two schools. On completion of the interviews all tapes were transcribed and a printed copy forwarded to each teacher for comment. They were free to delete or clarify any part of the transcript before analysis was carried out.

Research Questions

A series of questions was developed which focussed on five areas of research.

1 Have NSW teachers used or are currently using controversial issues as part of their science teaching?
2 Which controversial issues, if any, are of student interest, as perceived by teachers?
3 Could controversial issues assist students in gaining any understanding about the nature of science as perceived by NSW teachers? How?
4 Do teachers have any concerns about how controversial issues were handled previously, are handled presently, or how they ought to be handled in the future?
5 Do the issues of surrogacy and human embryo experimentation provide suitable contexts for student learning with respect to controversial issues?

Method

The use of audio tape was chosen as the data collection method because it was convenient and familiar to all interviewees. The interviews were loosely structured and questions were not necessarily asked in the order indicated in the findings except for those dealing with surrogacy and human embryo experimentation. These were asked last when the interviewees were more at ease with the interview protocol. The loose structure of the first part of the interview allowed for responses to be in-depth, reflective and relevant to the research questions, whilst still covering pre-determined areas as indicated. Considerable effort was made on the part of the interviewer to ensure that all questions were asked, that there was no undue pressure to respond to all questions and that leading was avoided as much as possible.

Sample

A group of biology teachers (7 male, 7 female) was interviewed. Although not chosen at random, the sample was representative in terms of school systems (comprehensive, selective, co-ed, single sex, government, private), years of teaching, variety of teaching experiences, and chronological age.

Procedure

The interview questions were discussed with several science educators from another University. Trial interviews were conducted both with them and with non-science teacher educators. The latter were used to ensure clarity of presentation.

Each high school teacher was interviewed for between 45-60 minutes either at their school, if they so wished, or at the University, if this was more convenient to the interviewees. Teachers were made to feel at ease before taping began via an explanation of the interview procedure and were given the opportunity to ask the interviewer any questions they wished. This was done in the hope that the interview to follow would proceed freely and easily for the interviewee. Very few changes were made by the thirteen teachers who returned transcripts. The interviewer assumed, therefore, that the sentiments expressed by the participants were accurate and a stable record of the teachers' views on controversial issues in school science at the time of the interview.

FINDINGS

Discussion of the findings is now presented. General trends will be reported rather than individual comments except where specific points need to be mentioned.

1. Previous Thoughts on Controversial Issues (C.I.)

Have you ever thought about how C.I. might be taught in your classroom?Could C.I. be used in your science classroom? Most teachers indicated that they had thought about using controversial issues. Some indicated that they had always been able to deal with these issues as the arose, others indicated that once they had more teaching experience they dealt with the issues, whilst others did not regard controversial issues as part of their teaching because these issues were not specifically stated in their teaching programs. Controversial issues themselves were not seen to be the difficulty. However, the depth of coverage depended on the particular issue, the class in question, the available time, and the constraints of the syllabus.

2. Naming Controversial Issues in Science

Can you name some C.I. which you think might be associated with each of the four traditional sciences or with any inter-disciplinary areas in science?Which do you think are the more important ones? Can you give reasons for your choice?

Table 1 is a compilation of all the controversial issues mentioned by the interviewees in order of importance to them as science teachers. For example, controversial issues in the area of human reproduction, mentioned by thirteen teachers, were seen as the most important area in biology because they directly concern students at this stage of their lives. Twelve of the interviewees mentioned at least one controversial issue in each of the four traditional science disciplines as well as reasons why. According to some teachers, apart from the issues of scientific fraud, the politics of science and the use of money resources for scientific research, all other controversial issues are embedded somewhere within the Year 7 -12 science syllabuses, however obscurely.

3. Learning science from Controversial Issues

Might science be learned from some of these C.I.? Could they learn anything else do you think?

Three key points were mentioned by the respondents - the nature of science, scientific methodology and some affective areas. With regard to the nature of science, teachers pointed out that science is everywhere, it is dynamic and has strong links with technology and society. They also indicated that all these aspects needed to be reflected in science teaching and controversial issues would certainly help here. Scientific methodology was seen by teachers more in terms of potential. Four areas came out of the analysis of the transcripts - students could take on an active part in their understanding of scientific methodology, they could take on a more passive role via the critical examination of second-hand data, they could appreciate that the history of scientific ideas is closely linked with science methodology, research and discovery and, finally, that controversial issues add another educationally worthwhile dimension to school science. To quote from two teachers:

> Controversial issues give science methodology and the process of science an added dimension.
>
> The simple model we present in schools as science isn't how it really works.

TABLE 1
PRIORITY CONTROVERSIAL ISSUES FOR TEACHERS

Discipline (n=14)	1st	2nd	3rd	4th
Biology (13)	Human Reproduction	Genetics	Evolution	AIDS/euthanasia
Physics (11)	Nuclear Energy	Radiation	Nuclear Weapons	Big Bang
Chemistry (11)	Nuclear Energy	Chemical Pollution	Locations of factories	$ power of multinationals
Environmental Studies (10)	Pollution	Ecology	Greenhouse/ozone	Logging
Geology (11)	Mining	Time Scale	Fossils	History of the Earth
Others (3)	Use of $ Resources	Scientific fraud	Politics of Science	

In the affective areas, teachers made mention of the following with respect to controversial issues:

- the importance for students of making an informed decision
- an awareness and tolerance by students of other people's views
- the value of stirring up debate and hence fostering students to think
- the development by students of skills which allow them to formulate their own views on a long term basis.

To quote from one interviewee:

> ... probably more science can be learnt from one single controversial issue than anything else because..... you have to do a lot of research, ...talk to people.... collect information..... make judgements .... analyse ....start sorting .... you've got to decide well, what do I think ... and then form an opinion, that's the really good thing about controversial issues, can't sort of sit on the fence and say "Yeah, well I love forests but I think paper is really important too..."

4. Students' Interest as Seen by the Teacher

What do you think your students would be interested in? Why?
(Optional: Ought they to be interested in any of the others? Would you like to expand on this?)

On analysis of the transcripts five areas emerged:

- Students' interest at the moment. It was generally agreed that any controversial issue that directly concerns them now is of interest and importance. Usually these interests are found outside of what some might term traditional science teaching, for example, issues concerning sexuality. Controversial issues were seen by teachers as probing students at a personal level and hence challenging them to step outside their personal "comfort zones". Mention was made of the interest and energy of students with respect to some of the controversial issues and how we, as science teachers, might harness this for what science could be learned from teaching about controversial issues.

  Issues which students ought to be more interested in included the environment and nuclear technology. Smoking was considered as a non-issue since students already regarded it as a health hazard. Teachers saw the issue of human embryo experimentation as being of possible interest to students.

- Students' reaction to controversial issues when presented by the teachers. As might be expected, responses varied between interviewees depending upon their own teaching experiences. Some teachers responded by saying that, on the whole, students were excited and interested in controversial issues. They were knowledgable in some areas, generally mature in their approaches, and willing to discuss their opinions and ideas with peers. Other teachers were concerned that students responses were often highly emotive, lacking in thought and logic and frequently borrowed opinions. Some were also concerned that their students either were not willing to participate in class discussion for whatever reason, did not have an opinion, or were generally apathetic in their attitudes to controversial issues.

- Influences on Student Decision. Frequent mention was made by teachers concerning the media in its often incorrect, diluted and simplified versions of scientific issues. It was seen as fostering erroneous, misleading scientific values and student misconceptions. The equating of the greenhouse debate with the ozone debate was sited as one such example. Environmental issues, whilst still of major importance, were seen by teachers as being overdone and so created boredom on the part of some students. Parents, who were themselves often misinformed about scientific issues, were seen as a concern. These incorrect views, when adopted or borrowed by their children, were seen by teachers as difficult to shift and to deal with. The role of the Church in some private schools was seen as a major concern, particularly when moral or ethical type issues were brought up in the science classroom.

- Students' Perception of Science. Not surprisingly, teachers felt that the stereotypic view of science and of scientists held by some students was not helpful. Students continued to see science as having no relevance now or in the future. Students need to have a broader view of science and to realise that decisions made now have future implications.

- Differences between boys and girls. Half the teachers interviewed made some mention of this. Girls were seen by teachers as being more interested in I.V.F. type issues and often showed empathy for those affected by infertility. Boys were seen by these teachers as being more removed from the situation. They were more interested in the monetary cost of the technology. One teacher was quick to point that any mention of the possibility of the students' own infertility could be seen by some boys as a "non-event".

5. Current and Previous Use of Controversial Issues

Have you used C.I. in your own science teaching?
Can you tell me more about this?
Did the students ever suggest any C.I. themselves?

A wide variety of comments and examples was given here. Some teachers saw themselves as the centre of class discussion and debate. They also gave their viewpoint when appropriate. Others used controversial issues to stimulate student debate and group work. These classes were still managed and directed by the teacher but the teacher did not necessarily control the flow of discussion. Another group of interviewees had allowed students to structure the lessons and control classroom debate. Here, the role of the teacher was merely that of overseer. Whether or not students themselves suggested further controversial issues depended very much on the issue and the class involved. Table 2 illustrates how some controversial issues were dealt with by teachers.

TABLE 2

TEACHING TECHNIQUES USED BY SOME TEACHERS WHO HAVE USED CONTROVERSIAL ISSUES AS PART OF THEIR TEACHING

Issue	Teaching Technique	Science Content	Student Response
Cryogenics	Teacher Centred Discussion	Body Freezing (SA:V) Cost $ Geologically stable sites	High interest, excitement about the unusual Links with science clearly established
IVF/Pregnancy	Pregnancy Simulation. Students asked to carry an inflated balloon under their jumper for a lesson	Human Embryonic Development Mechanics of Birth	Boys/Girls more sympathetic to difficult and uncomfortable aspects of pregnancy
Animal Experimentation	Affected animal brought in	Affect of high levels of testosterone on male rabbit	Ethics/injustice of animal experimentation. Discussion of the term "pet"
Euthanasia	Visiting medical officer as guest speaker	Disease Life Support Technology	Euthanasia/terminal illness demystified. Outside expert well received

6. The "Best" Controversial Issues

Which of the C.I. that you've just mentioned would you consider the "best" ones to explore? Why?

A clear link was made by teachers between their responses to this section of the interview and that of perceived students' interests. Controversial issues certainly stimulate class discussion when they strike at the personal beliefs of students and are seen by students as socially and personally relevant. Because these issues are often highly emotive, they motivate discussion but not necessarily an ordered one. Another response by teachers was that the "best" issues are those that question the students' misinformed and set ideas. Controversial issues thus challenge students to formulate and re-formulate their ideas as the need arises. Other respondents regard "best" in terms of whether the controversial issue illustrated what science is like and the direction(s) in which science is heading. The following quote summarises the sentiments of respondents.

> There is no one issue of major importance. What is important or the "best" ones are those which make the students think and allows students to transfer skills across topics, other controversial issues and between other subjects at school.

7. Concerns about Controversial Issues

Might you have problems or concerns about teaching C.I.?

All teachers expressed concern about the teaching of controversial issues. Within the private sector teachers were concerned about the control that parents and the Church have over the curriculum particularly with moral-type issues. Two of the more experienced teachers resented this influence and thought it unnecessarily intruded on their professionalism but found other ways to broach these topics. It was noted by one of these experienced teachers that global issues such as environmental pollution were also moral issues but they would not need to seek school approval to broach these in class, unlike those concerned with human sexuality and reproduction.

Government teachers had no concerns with these moral issues. Their concerns dealt with whether some issues were suitable for the younger students. Concern was also expressed with regard to time and syllabus constraints in the senior years. Lack of adequate, up-to-date teaching resources, general lack of in-service programs and students' misinformation added to the problem. Despite these set-backs, teachers were still, on the whole, willing to present and discuss controversial issues, if and when the classroom situation was appropriate.

8. An "Ideal" Situation

What would school science and science teaching be like if C.I.s were more prominent in the curriculum?
How would you ideally like to teach C.I.s?

Interviewees indicated three areas of response to the question concerning school science and science teaching. The first dealt with the student, the second with teaching and learning, and the last with themselves as teachers. With respect to students, teachers indicated that if controversial issues had a more prominent place in the science curriculum, students would have more opportunities to debate, think independently, speak their minds and formulate opinions, provided the issues were seen by them as topical. Even the unmotivated and reluctant learners might find interest in the topic and thus be able to "discover the science" embedded in the issues. Teachers indicated that these issues would broaden students' horizons, and hopefully allow significant transfer of skills between other issues. This was seen as a valuable learning experience for all students.

From the teaching and learning perspective, teachers felt that controversial issues would contribute so much more to traditional academic subjects because school science is now about what is "on the edge" of scientific research. Science teaching would ideally become more productive and purposeful because students would be more involved in their own research. The learning of science in this 'ideal' situation now begins from a context containing controversial issues rather than from the traditional approach where, often, the controversial issues are presented as an adjunct.

From the teachers' perspective, school science might initially involve a change of role from that of sole provider of information to that of facilitator of information. The more difficult aspects would include the necessary time needed for lesson preparation since up-to-date information needs to be gathered and analysed for student suitability. Given the perceived lack of readily available information, successful implementation would be time consuming. It would also be difficult to keep some students on task if they no longer regarded the issue as controversial.

How would teachers ideally like to teach? Interviewees would appreciate the time and resources to develop educationally sound programs dealing with controversial issues without the constraints of syllabuses and external examinations. Students given basic teacher direction would work in co-operative groups on specific research tasks, modelled on what might occur in scientific research. Students would discover for themselves the joy of learning. As one respondent stated: "It would be fantastic, the sky's the limit."

9. Who Decides Which Controversial Issue to Use?

Who decides which C.I. to choose if you're going to have C.I. in your classroom?Are you able to broach all issues at your school?

Generally, it is the science faculty rather than individual teachers who decides which controversial issues are placed in the school's science program, especially if student assessment is involved. For any moral issue, teachers in Government schools felt free to incorporate these into their programs after giving due regard to the socio-ethnic background of their students. In contrast, those at Church schools, would need to consult , for example, the school executive.

10. Teacher Roles

What new or different roles might you as a teacher have in a C.I. classroom?
Would you be comfortable with these?

Respondents indicated that they would be comfortable with the many and varied roles provided that they were adequately prepared in all aspects of these roles. The roles included helper, provider and facilitator or information, neutral chairperson, devil's advocate, counsellor and, possibly, that of a parent. The point made by those who responded was that they would take on these roles provided they motivated and stimulated students to learn.

11. Aims

How would you or have you gone about creating the aims for a science department which wanted C.I. to be embedded in the science program?
Did you see C.I. as a separate topic like energy, force?
If C.I. went "in", would anything be "deleted"?

Interviewees stated the aims but did not specifically indicate how they would be created. Teachers felt that students should:

* have available recent information about controversial issues so that they are able to formulate their own opinions and be appreciate of the views of others
* be shown the necessary skills for individual research and so be able to transfer these skills to other areas
* make well thought-out, rational decisions
* display a healthy suspicion concerning emotive arguments which try to resolve controversial issues
* come to realise that science has much to offer in terms of endeavouring to resolve real-life issues and conflicts.

The majority of teachers thought that controversial issues should be integrated, wherever appropriate, into science programs. Two teachers went further to indicate that, if controversial issues were well-integrated, then Science, Technology and Society issues might deservedly receive more emphasis and controversial issues themselves might lighten what is perceived by some students as "hard" science.

12. Surrogacy and Human Embryo Experimentation as Contexts for Teaching Science

Have you heard of these terms? What is your understanding of each of them?
What science/biology might be involved with surrogacy and human embryo experimentation?
What other areas might be involved outside that of science?
Do you think these topics have any potential for stimulating student interest and understanding in science? Why?
Do you have any reservations about teaching these topics? Why?

Surrogacy All teachers were aware of the term surrogacy and were able to give a broad definition in terms of a woman gestating a child for someone who is infertile. About half of the respondents defined surrogacy only in terms of its traditional meaning, that of the situation where the surrogate woman contributes her egg. Others defined surrogacy in terms of I.V.F. technology, where the gestating woman need not donate her egg. Only one teacher, who had used surrogacy as a topic within a unit on human reproduction, was able to clearly distinguish and elaborate on both meanings of the term.

Once the term was mentioned, most teachers were able to cite a range of associated terms such as mother, father, whose embryo, etc. One interviewee was very enthusiastic about the issue of surrogacy and was able to comment immediately upon how it might interest pubescent boys. Teachers listed the following areas in human reproduction where surrogacy could be mentioned: infertility, genetics, embryology and I.V.F. technologies. The majority of interviewees thought that students would be interested in this topic because it could provide an appropriate context in which to discuss recent advances in human reproductive biology. Class discussion of the terms mother, father and parent was seen as providing a springboard into the science involved with surrogacy. The reasons given by one teacher was that students could relate to the notion of what a mother, father or parent is without being a parent. This was in contrast to human embryo experimentation. Here the issue and its associated terms were seen to be more of a conceptual jump for students. Two teachers expressed strong reservations regarding the suitability of the issue for high school students. Others noted that they would closely monitor student interest; others would ensure that judgements on the morality of the topic were suspended; others would foster empathy with those involved, including the child; whilst others would tread warily because of strong ethnic-cultural differences between students.

Responses varied concerning the potential for learning and stimulating student interest. Some saw the potential in terms of taking students outside their "comfort zones" and thus challenge students' knowledge, opinions and thinking processes. Others emphasised the need to keep the science content and skills well to the forefront of each lesson in order to avoid the lesson becoming one concerned with morality. Mention was made of students being able to research information which might be new to the teacher. Finally, teachers emphasised the need to be sensitive to the students themselves, their families, and to the general school community.

Human Embryo Experimentation This topic was seen by teachers as extremely controversial, to be handled with great care and sensitivity and, to be presented only to able students in their final years of schooling. The strong moral, ethical and philosophical dimensions of the topic were cited as reasons. Teachers were familiar with the term and easily linked it with the science embedded in the issue. Mention was made of its links with the IVF programs and its use in the study of cellular differentiation and development and tissue rejection. Other areas included questions on the value of life, personhood, donation of gametes as opposed to somatic cells, the meaning of the term 'defective' and the question of who decides what research is carried out.

Human embryo experimentation was seen as having the potential to question students' fundamental beliefs concerning the meaning of life in a very positive way if handled with care and sensitivity.

CONCLUSION

The majority of teachers in this study were of the opinion that the teaching of controversial issues in school science had much to contribute to student learning and enthusiasm for science. Analysis of the transcripts indicated that these teachers were willing to use controversial issues in their teaching provided that there was curriculum support. Many teachers felt that such materials were not readily available. The interviewees who had used controversial issues were aware of or were already employing some of the teaching techniques mentioned in the literature (Solomon, 1991; Solomon & Swift, 1990; Ramsey, Hungerford & Volk, 1990). These teachers also emphasised the need to develop tolerance and decision making skills in students as part of the teaching of controversial issues (Brinckerhoff, 1990).

The issues of surrogacy and human embryo experimentation were considered by these interviewees as potentially suitable controversial issues for discussion in school science.

These and other areas of assisted reproductive technologies were seen as areas for science education research because of their potential in understanding how students might better understand science.

Using controversial issues in science commits the teacher to dynamic, innovative teaching and the student to effective learning. Effective teaching does not imply passive learning. Establishing a balance between the students' interests and desires with the teachers' other professional responsibilities remains challenging. Controversial issues focus on problems and possible solutions making them a valuable tool for stimulating students to think about and to enjoy learning science.

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TEACHER PERCEPTIONS OF PROFESSIONAL DEVELOPMENT NEEDS AND THE IMPLEMENTATION OF THE K-6 SCIENCE AND TECHNOLOGY SYLLABUS

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ABSTRACT

This study examines teacher perceptions regarding professional development practices used in a region of the NSW Department of School Education to support the implementation of the K-6 Science and Technology Syllabus. The findings from a survey of 97 teachers indicate that teachers have a preference for 'traditional' models of in-service which may not bring about significant changes. Teachers also perceive that change is brought about through the influence of external factors such as in-service and resources which are not directly the responsibility of individual teachers. This contrasts with the perception that the inability to change is due to internal personal qualities.

EVALUATIONS OF SCIENCE TEACHING AND PROFESSIONAL DEVELOPMENT

Two recent NSW evaluations, *Investigating: Science K-6 Evaluation* (NSWDoE, 1989), and *Program Evaluation of Staff Development in NSW Government Schools* (NSWDSE, 1990) indicate serious concern for educational organisations which measure the success of curriculum implementation through changes in classroom practice (NSWDoE, 1989, p. 41). Concerns about the ability of schools to plan for the professional development needs of their staff, were identified in Program Evaluation of Staff Development in NSW Government Schools (NSWDSE, 1990). Curriculum implementation imposes substantial demands on educational organisations and at a more personal level, on the classroom behaviour of individual teachers (Renner, 1990). The considerable funds and time "spent on the development of new curricula are largely wasted unless there is equal consideration accorded to their implementation" (Renner, 1990). This wastage would be compounded if funds and time were wasted on ineffective professional development programs.

The In-service Teacher Education Project, initiated by the former Commonwealth Schools Commission (cited in Carrick, 1989, p. 195) described in-service programs commonly used in Australia, as having the following features:

- one-off conferences which do not have follow through and recall...;
- topics ... frequently not well connected with the priorities of schools;
- follow-up support for ideas and practices introduced in programs occurs in only a very small minority of cases;
- programs rarely address the direct needs and concerns of the participants;
- the majority of programs involve teachers from many different schools or regions...;
- ... lack of long term and systematic planning of programs to ensure their effectiveness.

Given that teachers have generally experienced only the model of in-service described by Carrick (1989), questions arise as to whether they are in a position to purchase or plan professional development programs to support the implementation of innovations in science and technology education such as the NSW K-6 Science and Technology Syllabus (K-6 S&T)

(Board of Studies, 1991). The study sought to determine teacher perceptions of how their professional development needs in science and technology would be best met.

Teacher Attitudes and Practices in Science Education

Teachers in New South Wales experienced difficulties in implementing the 1980 'Investigating: Science K-6' policy because of a lack of understanding of the inquiry method, absence of core content in the policy and inadequate in-service. Lack of understanding of the processes involved in the inquiry method and poor teacher confidence in managing inquiry classrooms meant that most reverted to didactic methods and largely ignored the 1980 curriculum (NSWDoE, 1989).

Many studies (Sharon, 1987; Joyce, 1980; Bechtelheimer & Tamashiro, 1987; Goodrum, Cousins & Kinnear, 1992) have looked at the effect in-service programs have on teacher attitudes. Rennie, Parker and Hutchinson (1988) and Goodrum et al. (1992) found that Science in-service programs which focussed on teacher attitude, increased confidence and which supported and monitored teachers as they implemented programs in their classrooms, were able to produce changes in the outcomes for both teachers and students. K-6 S&T also introduces several new content strands. Skamp (1991) found that teachers lacked confidence in the new content strands and indicated the need to specifically address these new strands in pre-service and professional development courses.

Professional Development Practices in the Region

Braithwaite and Koop (1985) conducted a study in an administrative region within the NSW Department of School Education which appears to have an administrative structure and resource support identical to that which currently exists in the Metropolitan Region in this study. The most common form of staff development in both the Braithwaite and Koop study and this study was the after-school workshop or lecture, on a topic of general interest, held away from school, in a group setting with little accommodation to individual differences or The Metropolitan Region in this study has an in-service program to support the implementation of K-6 S&T, which reflects Carrick's description. According to Ingvarson this practice provides "a few thousand dollars for one-off in-service courses which could only be given to a fraction of the relevant teacher population. This is crazy" (Ingvarson, 1987). Ingvarson describes such in-service practices as a 'cottage industry' and stresses the need for it to become "a central component of system level planning and coordination of all resources relevant to the support of innovation, school improvement and professional development" (Ingvarson, 1987). Since 1989, the advent of staff development days has involved principals and teachers in developing professional development programs which can be delivered at the school level. It appears that programs developed for these days duplicate the in-service practices described above.

CONDUCT OF THE STUDY

A survey seeking information concerning teachers' beliefs, attitudes and practices in relation to the 1991 K-6 S&T policy was administered to 97 teachers participating in the PRIMESTEP (Primary Science and Technology Education Program) School Based Professional Development Program. In contrast to the usual 'one-off' in-service course, PRIMESTEP is an extended professional development program, developed for the NSW Department of School Education as a joint project by the University of Western Sydney and the Metropolitan West Region specifically to support the implementation of K-6 S&T. Forty PRIMESTEP leaders, four from each of the ten administrative regions were trained to deliver the school based course.

Many questions used in the survey were based on those previously asked by Rennie et al. (1988). Others were drawn from an evaluation study carried out by the Department of Education (NSWDoE, 1989). The surveys were handed to all participants who attended the PRIMESTEP School Based Course during Week 9 of Term III, 1992; 97 completed surveys (97.8 %) were returned.

Women appear to be over represented in the sample (87.6%) compared to the gender balance of primary teachers as a whole. This may be because older women are more likely to be 'growth seeking' than their male cohorts (Howser, 1989) and therefore more likely to be represented in a sample drawn from teachers actually participating in an after-school in-service program. Alternatively, male teachers, in contrast to their female cohorts, may feel more confident in the area of science and technology and may feel less inclined to engage in professional development activities in this area. Rennie et al. (1988) found that female teachers tended to be less confident of their own abilities and knowledge in science, particularly in areas related to the physical sciences. This lack of confidence, combined with the growth seeking attitude identified by Howser may account for the over-representation of women in the sample drawn from the PRIMESTEP School Based Course.

A quarter of the teachers surveyed were members of the school executive (Executive Teachers: 10.3%, Assistant Principals: 10.3%, Deputy Principals: 4.1%). The remainder were classroom teachers, not holding executive positions in their schools. Nine (9.3%) held the position of Release from Face-to-face (RFF) Teacher and were teaching science and technology for their full teaching load. The significance of the practice of using RFF teachers to teach science was commented on by the Department of Education in the 1989 evaluation as one which led to many classroom teachers "not having the opportunity to acquire and practise the teaching skills that are essential for proper implementation of the policy". It also made the teaching of science "someone else's responsibility" (NSWDoE, 1989).

Teacher views on professional development programs.

Teachers were asked an open-ended question, 'What do you believe is the best way to introduce the Science and Technology Syllabus document to teachers?' Eight categories of

TABLE 1

BELIEFS ABOUT THE BEST WAY TO INTRODUCE THE S&T DOCUMENT TO TEACHERS

RESPONSES	COUNT
a. Responses indicating where and when the course should be delivered	
In-service courses	25
Staff development/pupil free days.	22
At school, school based, in staff meetings,	17
Total	64
b. Responses indicating what should be covered in the courses	
Through practical activities, demonstrations/workshops.	33
By providing prepared teaching/program units.	10
Total	43
c. Other	
Gradual in-service with follow-up.	13
Sharing ideas, doing it with class, special centres	7
Courses such as PRIMESTEP	1
Total	21

responses were identified, falling into two broad groups (Table 1): responses indicating the point of delivery, i.e. where and when the courses should be held, and responses related to the content of the course.

Where the courses should be held

Thirty nine participants (40.2%) responded that the best way to introduce new syllabus documents is to do so at the school, at staff meetings and on staff development days. There is a clear desire to have professional development activities delivered in the work-place context. This confirms the findings of the Program Evaluation of Staff Development in NSW Government Schools which found that; "School Development days were rated by the vast majority of both primary and secondary (teachers).... as the most important strategy in their staff development program" (NSWDSE, 1990, p. 12).

Course content

The responses indicate that teachers believe that K-6 S&T should be introduced through the use of practical activities involving demonstrations and workshops. These responses suggest that the teachers in the sample are aware of the 'hands-on' nature of the syllabus and some of its implications for the classroom. The responses also suggest however, that teachers may feel that practical activities are all that is needed to teach science and technology in primary schools. In the words of one respondent, "teachers need to be shown 'how to do it' in their classrooms". Only thirteen (13.4%) participants suggested that the best way to introduce the syllabus was through gradual in-service with follow-up. These responses may reflect a lack of understanding of the needs of teachers when implementing major changes such as those embodied in both the previous science policy and the current syllabus.

Teachers in the sample appear, in the main, to endorse the in-service practices which have predominated within the region, even though they themselves were participating in the fourth week of the PRIMESTEP School Based Course which is a gradual in-service with follow-up. Not one teacher expressed a desire for courses to contain details of the learning theories behind the new syllabus. Only one participant suggested that courses such as PRIMESTEP were the best way to introduce new syllabus documents. This contrasts with the evaluations from many regions of the PRIMESTEP Course itself which have been overwhelmingly positive.

The delivery of professional development programs

To determine perceptions regarding the most effective modes for professional development programs to support the implementation of the Science and Technology Syllabus, participants were asked to rate the effectiveness of eight different modes for professional development programs on a five-point Likert scale where 1 = ineffective and 5 = effective. A *mode* was defined as the method of delivery or the structure of the course as distinct from the content of the course. Sessions at professional development days were ranked highest by the participants (mean, m= 4.0) while an accredited course run through a university was ranked the lowest (m = 2.8). Sessions at staff development days were rated as the second most effective method of supporting syllabus implementation. ANOVA with repeated measures was used to compare the ratings of the different professional development modes.

Table 2 ranks the modes according to the mean ratings on the effectiveness scale. Significant differences were found between the mean ratings of the professional development 'modes' (F between items 10.27; df=7, 504; p< .0001). Follow-up comparisons using the Scheffe test

TABLE 2
PAIRWISE COMPARISON OF EFFECTIVENESS RATINGS

Professional development days	An intensive one day course	An extended program	Modules delivered by a member of staff.	Observations of programs in other schools	Several short after school sessions	An accredited course run through the PDC*	An accredited course run through a university
4	3.7	3.6	3.6	3.6	3.2	3.1	2.8

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* (PDC) The Professional Development Centre

revealed significant pair-wise differences as shown in Table 2 where any two means not joined by asterisks are significantly different (p<.05).

Accredited courses run through the Professional Development Centre (PDC) or a university are rated as significantly less effective than all of the other types of courses, other than short after-school sessions. Staff development days and intensive one day courses are rated as significantly more effective than accredited courses. One of the reasons why PDC courses and accredited courses at a university rate significantly lower than day courses may be because they take place generally after-school and require a commitment of time by the individual teacher. A question arises as to whether the use of the word 'university' in one of the options may have resulted in a lower ranking by the participants. Does it reflect teachers' perceptions about the perceived ability, or lack of it, of universities to provide effective courses to support the implementation of the Science and Technology Syllabus? The responses may suggest that such courses, or universities, may have an image problem. It may be that this perception exists towards universities as providers of professional development courses for teachers in general and not specifically towards science and technology. Further research is needed to clarify this issue.

Participants' preferences for professional development on staff development days in response to this question confirm the responses indicated in Table 1 where teachers expressed the desire to have professional development activities organised for them during the day and at the workplace. A question arises as to whether these responses reflect a lack of understanding of the needs of teachers' when undertaking significant changes or innovations? It can be argued that these responses reflect a perception that teachers feel that the Department or the school, as opposed to individual teachers, is responsible for meeting individual teacher needs to implement the K-6 S&T? If this is so, it suggests that teachers perceive that the implementation of the syllabus is largely the responsibility of the 'system' rather than of individuals.

The content of professional development programs

Teachers were asked to rank nine different types of professional development courses on the basis of the importance of the content on a five-point scale where 1 = unimportant and 5 = important. The means for each of the nine types of courses are shown in Table 3. Significant differences were found in the ratings of the content of the professional development courses suggested. ANOVA with repeated measures was used to compare the importance ratings of the nine options. Significant differences were found in the importance teachers assigned to the various types of courses. Table 3 ranks the content according to the importance mean derived from teacher rankings of the importance of the different types of courses suggested. Significant differences were found between the ratings of the courses (F between items 58.4; df=9, 688; p< .0001). A follow-up Scheffe test revealed significant pair-wise differences as shown in the table, where any two means not joined by asterisks are significantly different (p<.05).

Participants clearly indicated it was more important for courses to contain a variety of formats (m=4.6), mainly practical activities (m= 4.5), involve opportunities for 'teacher-teacher' interaction (m=4.5), and which involve applying ideas between sessions (m= 4.3) were ranked significantly more important than courses which contained a detailed theoretical base (m=2.5), an awareness of change in adults (m=3.6) and opportunities for guided reflection (m=3.6). The responses to this question reiterate the results in Table 1 where the use of practical activities was considered by almost a third of participants to be the best way to introduce syllabus documents. The significant 'unimportant' rating given to courses which provide a theoretical base further reinforces teacher preference for practical courses. However, the lack of "understanding and translation into teaching practice of the basic philosophy of inquiry and process learning contained in the policy" (NSWDoE, 1989, p. 12) was identified as one of the most significant reasons why the past science policy was not effectively implemented in NSW.

TABLE 3
COMPARISON OF THE IMPORTANCE OF DIFFERENT TYPES OF CONTENT

Have a variety of formats	Use mainly practical ideas	Involve teacher-teacher interaction	Involve applying ideas between sessions	Require support particip-ation of executive	Involve demon-stration	Involve guided reflection	Aware-ness of change in adults	Provide detailed theory
4.6	4.5	4.5	4.3	4.0	4.0	3.6	3.6	2.5

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Items joined by asterisks (*) indicate no significant difference

It is possible to view the nine different types of professional development courses defined in the question as those which require greater involvement of individual teachers and those which are perceived as being the responsibility of the system in the change process. Teachers rate 'internal' aspects of change, such as understandings of the theory behind the syllabus, change in adults and guided reflection as significantly less important than the more 'external' options suggested such as 'practical ideas' and the 'format' of the course. Given the choice, it appears that teachers would prefer practical courses, which reflect 'awareness of change in adults' but are devoid of 'detailed theory', which are delivered on staff development days' at school. While such courses would appear to satisfy teachers immediate needs for 'practical' activities and would allow some immediate application in the classroom, the absence of any theory could jeopardise the long term success of the innovation. It may also suggest the construction of a dependent relationship between classroom teachers and the developers of professional development courses. Courses which provide practical ideas satisfy immediate needs and are regarded as effective and important by teachers, but the absence of theory in such courses creates a dependence on the supply of further practical ideas. The providers of such courses feel that they are satisfying a perceived need and the consumers of the courses perceive that their needs are being met. Such perceptions may be misleading.

Regional In-service programs/courses

Almost half of the teachers in the sample had attended regional in-service courses and of these over 65% had attended more than one course. All were in the fourth week of an extended in-service course. Participants were asked to rate the effectiveness of the courses they attended on a five point Likert scale and to provide reasons for their ratings. The mean effectiveness rating appears to be very high (m=4). The responses were grouped into the five categories shown in Table 4. Effective in-service courses were perceived, by 41% of the participants who attended them, to be those which used 'practical activities'. Approximately one third of the participants rated the in-service courses as effective because they were motivating, increased their confidence and enthusiasm for teaching in science and technology. The provision of practical ideas seems to account for their high effectiveness rating.

TABLE 4
REASONS FOR THE RATINGS GIVEN TO IN-SERVICE COURSES

Category	Number
They were practical	17
Gave me greater understanding/confidence/motivation	14
Well presented and organised	7
Resources are not available	2
I knew it all already	1

Teachers were asked an open-ended question to indicate what they personally believed they needed to implement the Science and Technology Syllabus in their classrooms. The responses were grouped and categorised. These responses indicate that teachers equate needs in relation to syllabus implementation with external factors such as resources, money (presumably to purchase resources and materials) and practical ideas contained in teaching units (see Fig. 1). Interestingly, these responses also suggest that teachers have a particular image of science and technology education, i.e. it involves resources (which presently they don't have), money, takes a lot of time and requires special teaching units. Many teachers may have already identified reasons in their own minds why the science and technology syllabus cannot be implemented in their classrooms.

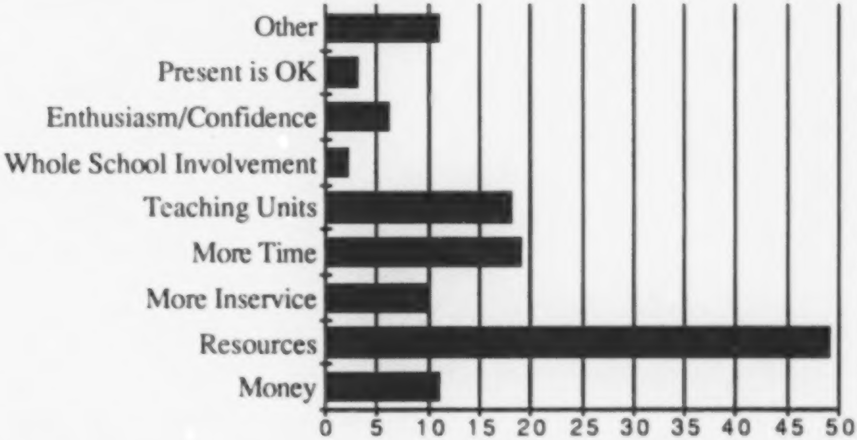

Fig. 1. Categories of perceived teacher needs to implement K-6 S&T in their classrooms.

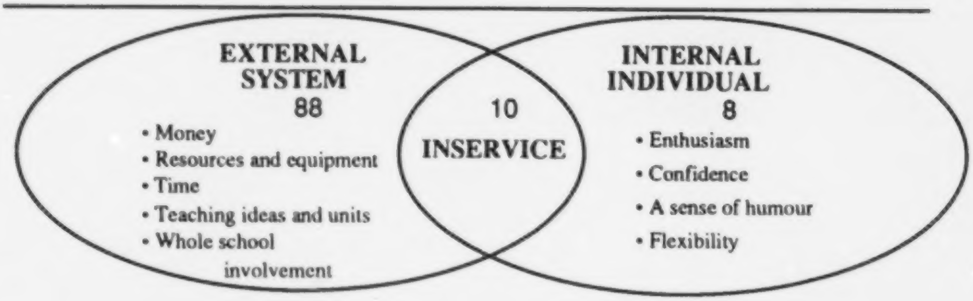

Fig. 2. A model of teachers' perceived needs in relation to implementing K-6 S&T.

The expressed need for resources, more time, teaching units and for whole school involvement are external factors; perceived as not the responsibility of individual teachers. In-service, which it could be argued is an external factor, but requires the commitment of individual teachers. Relatively few teachers appear to perceive their own role as a critical or important factor in relation to implementing the science and technology syllabus. Only seven teachers mentioned confidence as a need. Very few teachers identify their own personal involvement in the process of change needed to implement the syllabus. The responses suggest many teachers believe that if all the external needs are met; that is, if the resources, time, teaching units and short practical in-service courses are provided, then the syllabus will be implemented. While teachers are individually responsible for attending them, in-service courses provided by the region or the school are perceived as not the responsibility of the individual teacher. In the main, the responses suggest that the responsibility for implementing syllabus documents is not a function of internal changes in individual teachers, but of external changes which are perceived to be responsibility of the school or the system (see Fig. 2).

TEACHER CHANGE

The teachers were asked to indicate what percentage of their colleagues were changing their classroom practices as a result of the science and technology syllabus. The teachers who responded to this question (65) appear to be optimistic about the number of their colleagues who are changing their classroom practices. The mean of the estimates of teachers changing their classroom practices was 58.2%. The range for the sample, from 1% to 100% indicates that there is a big difference between teacher perceptions regarding the number of their colleagues who are changing. Personal characteristics or attributes, as indicated by the data in Table 5) were identified by the teachers in the sample as the reason why some teachers were reluctant to change. Whereas in response to earlier questions, teachers had associated the implementation of the science and technology syllabus with external factors such as resources, time, practical ideas and teaching materials, the inability of others to implement the syllabus was associated with internal or personal attributes such as colleagues being "set in their ways", "unable to cope with the children's freedom", "the mess", "the noise", or because of fear or a lack of confidence. It suggests that the teachers surveyed consider that change occurs because the external factors which they believe facilitate change have been present, but when teachers cannot change its because of internal factors.

TABLE 5
TEACHER PERCEPTIONS OF WHY SOME TEACHERS FIND IT DIFFICULT TO CHANGE

Reason	Number
Dislike of mess/noise	19
Set in their ways/routine/style/lazy/resist/attitude	18
RFF Teacher teaches S&T	4
Inability to cope with children's freedom	3
Problems with resources/equipment	3
Lack of skills (group work, knowledge, tools etc)	3
Lack of confidence/fear	2
No response	26
Other(lack of opportunity, takes time, gradual, too much)	9

IMPLICATIONS

Teachers perceive that their needs in relation to implementing K-6 S&T can be met through the provision of one-day in-service courses held preferably in their respective schools on staff development days. This belief may place unrealistic expectations on the in-service courses and on the teachers participating in them. A perception appears to exist that one-day courses involving practical activities should be able to provide teachers with all they need to implement innovations such as K-6 S&T.

A dependent relationship has developed between those who develop professional development courses and the teachers and schools who 'consume' them. Because the in-service model used in the region invariably focuses on meeting teachers' perceived needs it appears to provide them with what they want without necessarily producing changes in classroom practice. If significant changes in science and technology education are to occur, a better way of determining professional development needs, which integrates the "basic philosophy" (NSWDSE, 1989) and "long term and systematic planning to ensure their effectiveness" (Carrick, 1989).

The expressed belief that external factors will facilitate the implementation of the syllabus can be contrasted with the significant degree of unimportance placed on the development of theory, either relating to the innovation itself or to understanding the change process in adults. Teachers' lack of understanding of the learning theory underlying the current science and technology syllabus, and the lack of understanding of theories of adult change inevitably means that the implementation of K-6 S&T will be compromised.

Investment in syllabus development is an expensive process which is largely wasted if not supported by the use of professional development strategies which will bring about sustained changes in classroom practices. Major system-wide innovations such as K-6 S&T may not be implemented fully and effectively in schools if the same practices which were used to support the implementation of the previous science policy, and which teachers perceive to be appropriate are employed. The beliefs and attitudes revealed in this study raise questions about the way teachers perceive their responsibility in the syllabus implementation process. Teachers and school administrators need to appreciate the theory and philosophy behind the various syllabus documents but this is often overlooked as teachers focus on meeting their immediate needs for practical ideas and resources and seek the most inexpensive way of meeting these needs. Consequently, while teachers' immediate needs may be met, their long term needs are overlooked and perpetuate their dependence on current but discredited in-service practices. The challenge is not so much to develop professional development programs in science and technology, such as the PRIMESTEP Course, which address the perceived needs of teachers, but to have these courses implemented on a system wide basis.

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TAKING THE PLUNGE INTO THE GENE POOL: TEACHING AND LEARNING IN GENETICS

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ABSTRACT

Genetics is an area of science that causes problems for children. This paper reviews initial findings from research into children's views of how inheritance works and the role this plays in their overall view of genetics. The implications these results have for the traditional approach to genetics education are outlined. An alternative approach is proposed.

INTRODUCTION

Genetics is an area of increasing impact on our lives. Examination of work by other researchers, classroom experiences and discussions with other teachers reveals that genetics poses problems for high school students. Genetics is perceived as complicated and difficult, yet genetics terms are increasingly appearing in everyday language. There is strong anecdotal evidence that the view of genetics presently taught in schools and the genetics that is widely discussed in the media are too different for effective learning to occur. The dominance of Mendelian genetics, particularly in lower secondary education, may no longer be appropriate; the personal experiences of the learner, and the ideas about genetics that arise out of those experiences, do not seem to promote understanding of the science ideas typically introduced in genetics.

Science should no longer be viewed as an elite discipline to which we gain entry through some gateway, but rather as an area of understanding to be opened up for all. Genetics can be presented to illustrate the elegant and elite development of scientific ideas. Genetics also plays an important role as an essential area in developing science for all, since it affects everyone. People will be expected to judge the safety of genetically engineered organisms, and the morality of gene therapy. Almost everyone will come into contact with detrimental genetic effects during her or his lifetime. A basic understanding of genetics will help people make more informed decisions, and have more control over their lives.

This paper reviews existing genetics education research findings and their relationship to the present research. The ideas that have surfaced as a result of interviewing children are discussed and their implications for the next stage of the research are outlined.

LITERATURE IN GENETICS EDUCATION RESEARCH

By far the majority of researchers are looking at ways that present learning in genetics can be made more successful, how the curriculum material can be more effectively learned and understood by the students. The presumed expectation of specific content as a grounding for students' tertiary education is reflected in this research into more effective teaching.

This focus leads to a large amount of research into 'misconceptions', by implication wrong ideas that need to be put right, and 'problem solving', finding ways to solve set problems more effectively. Some of the research suggests that present teaching strategies may not help clarify concepts in scientific terms but may in fact create further 'misconceptions'. Inherent in these problems with teaching strategies is that teachers themselves have difficulty with genetics, particularly in the junior high school area where many of the teachers of genetics are not biologists (Finley, Stewart & Yarroch, 1982). There is evidence of inherent difficulties in the topic for both teacher and student (Longden, 1982).

A wide range of studies examine problem solving skills because of the high profile genetics problem solving has at the tertiary level and the importance that success in the problems has for further study in genetics. A disproportionate amount of this research work involves the search for suitable algorithms to ameliorate the difficulties, for example, work with high school students carried out by Slack and Stewart (1990). There is a link between the research into problem solving area and the study of misconceptions. Hackling and Treagust (1982, 1984) describe a wide range of misconceptions associated with genetics including reduction division, the cell complement of genes, and the concept of the gene itself. A smaller body of research addresses student understanding of genetics concepts, much of this following on from earlier work on inheritance by Deadman and Kelly (1978) and Brumby (1979).

Studies of learning in science over the last 15 years reveal that children come to science with a considerable repertoire of ideas about science concepts, and that teachers need to take account of these ideas when preparing teaching strategies if links are to be made between children's ideas and those of science (Osborne & Wittrock, 1983).

The present study is based on the belief that students' prior understandings of genetics influence their thinking and further learning in this area. These prior understandings reflect a child's interest in genetics, and more effective learning will take place if genetics teaching is based on children's interests and questions. Therefore a number of children have been interviewed to elicit their ideas about genetics and themselves, and teaching strategies will be developed building on the views exhibited in the interviews. It is hoped to create a learning environment where students' existing ideas and science fit more comfortably together.
The next section of the paper is an account of some interviews carried out to explore students' existing ideas.

THE PRESENT STUDY

The initial phase of the research involved interviews with 49 children aged from nine to 15 years from four different schools, a mixed primary school, two single sex intermediates, and a girls' secondary school. The schools were selected because the researcher was familiar with their curricula and the place of genetics in them. In the primary school the five children interviewed had had no experience with genetics curriculum before the interview. In the intermediate schools the 24 children interviewed had received instruction in basic inheritance ideas linked to characteristics during their first year at intermediate This included the ideas that the organism has a characteristic controlling mechanism, and that people have different characteristics as a result of this mechanism. The 30 students in Form 4 (Year 10) at the girls' secondary school (13-15 years) had studied genetic difference between individuals in terms of characteristics being determined by genes.

The interview began by showing a photograph of a human family with a similar ethnic base to themselves and a discussion of similarities between family members. This usually led on to discussion about the subject's family and resemblances between members. Photographs were also shown of twins, unalike siblings and differently-abled adults and children to focus ideas on characteristics. Because photographs tend to focus on external appearance the researcher introduced the idea of non-visible characteristics, things going on inside, if they were not volunteered by the subject. On average the interviews lasted for 40 minutes. If the concept of the gene had not been mentioned in that time then it was introduced at the conclusion of the interview.

CHILDREN'S VIEWS

Five key issues relating to children's views emerged from these interviews.

An holistic view of inheritance

There was an overall discrepancy between the way genetics is viewed by science and the views of the children. Whilst science takes the reductionist view and reduces genetics to invisible bits, the children view genetics holistically in terms of their individual personal characteristics. Whilst science tends to emphasise the stability of the genetic code through its expression, particularly in Mendelian genetics, children see themselves as unique individuals, very different from each other.

> [genes] ..they're growing from you and sort of they get their Dad's genes and their Mums genes and um...like when they're a baby they probably have their Mum's and their Dad's mixed together and then when they start getting older, then they start to make more and make their genes different and become themselves. **Girl 11 yrs**

Children have no alternative but to base their views on their own experiences. Social experiences for young children are a mixture of being told that they look like their parents and having their personal uniqueness praised and encouraged. Six of the children interviewed, presumably through emphasis on their unique nature, did not see themselves as similar to their family members. Some of the younger interviewees were sure that similarity developed from living together.

> I think it is because they are living together. because when she was born (girl in her class) she was bound to look a little bit, you would probably see the eyes alike or something like that, but when you are living like them you start shaping - if you really suit them, you like what they do and all, you start to mould in with what they think. **Boy 10 yrs**

Whilst the science view of characteristics sees humans as having individual genes that each produce a specific characteristic, that we are, in fact, 99% similar to each other, the children's' view sees the whole person, which includes their characteristics, each of us being very dissimilar.

An expressed characteristic view of humans

Children tend to view themselves as wholes whilst science tends to view them as composed of significant different bits. Research has shown that the concept of differentiation causes difficulty for children (Johnstone & Mahmoud, 1980). The lack of an intuitive view concerning cells means that it is not surprising that children have problems seeing themselves as an ever increasing mass of cells that are genetically the same but differentiate into their internal and external physical characteristics! In fact, nearly all of the discussion with children during the interviews centred around the external characteristics of the children. If internal characteristics were considered, these tended to be talents or personality.

> Like, I look more like my Mum and I have got her intelligence, like really dumb at maths. **Girl 15 yrs**

Somatic inheritance view

An early scientific theory held that characteristics were passed on via the body or somatic cells. Later scientists proposed that a special germ plasm was responsible for inherited features. Children reflect this early view. Many thought their parents passed something to you when you were born but seemed to emphasise the somatic aspects. The idea that is was part of their structure rather than information that they received and that the 'stuff' passed on differed in amount depending on its expression. For example, the mother had more influence if they were girls, and likewise fathers if boys.

> ..probably it will depend on whether they are female or male, they might have more of their father's genes if they're male than their mother and the other way round if they are female. **Boy 12 yrs**

Science tends to emphasise the importance of what underlies what you can see, the hidden genes and what can be passed generationally i.e. the germ plasm. Children emphasise how the presence of the gene makes their characteristics. In studies of populations it is the probabilities of each genotype that are calculated, from which the phenotype is inferred, rather than what actually appears in the flesh. Children place their emphasis on what exists.

A non-replication, non-differentiation view

Many of the comments indicated that the children did not see genetic material as capable of multiplying. This misunderstanding or lack of a concept of replication can lead to explanations at odds with the scientific view. For example, to make a new individual will mean giving up genetic material.

> Your mother could have genes and then when she had you she would pass on some of her genes to you...she has to keep some for herself...like knowledge. **Girl 15**

Replication is a central concept of genetics and provides for a full complement of genetic information in every cell. The information needed for the functioning of that cell is then selected by the differentiation process and the cell takes on special characteristics.

The view of genes as structure rather than information

A strong theme running through the interviews was that the children viewed genes as structures that had to be present rather than information that had to be acted on. They reflect a view that could be summarised by 'if I am to be as I am then I need my own gene 'stuff'.
The children perceived that genetic information must be present to make up the characteristics and absent if the characteristic changes:

> I think that everyone gets the same genes as their father and mother .. except that they reproduce and make new genes as you grow older as well....I think it's just as you start to grow older, your hair gets longer, you might get another gene because you get more hair or it might change colour... your hair might start falling out and you lose a gene. **Girl 12 yrs**

Larger amounts of genes have to be there if you want more of a characteristic:

> Like with horses, like if you take after your mother, the mother gives you more. **Girl 14 yrs**

The gene has to be physically present in the right place to increase a characteristic:

> I think that probably like a kangaroo would have more genes in his legs to be able to jump harder.. **Girl 13 yrs**

As a person gets larger then there is need for more genetic material:

> [growing genes] They get bigger. They grow stronger to help you **Girl 11 yrs**

As a person grows changes in characteristics are due to new genes being made or changed:

S Because hair is different. Maybe one changed in the process or something because he has got straight hair and he has got more curly hair so maybe he started off with straight hair, or something like that.
R Why , do you think genes change?
S Oh yes, I think they do because my Mum said that when I was born I had blue eyes and they gradually went brown. **Boy 11 yrs**

Children have difficulty conceiving that there is a full complement of genetic material, i.e. the same stuff, in each cell. Even if they accept that they are made of many cells, it is 'obvious' that the cells must be different in different places because their body is different in these different places. Children appear to have no framework for working out how the cells become differentiated using the same genetic material. While children with the previously discussed views of genetic material find this process difficult to understand, they can be quite adept at the algorithm to solve a Mendelian problem.

This is not surprising when typical teaching is explored. At a lower secondary level the typical approach to genetics is to talk about both mitotic and meiotic cell division as a series of stages involving chromosomes in characteristic arrangements. The New Zealand examination prescription for Form 5 merely expects students to recognise the order of the stages. There is no preliminary discussion about whether there are cells at all and the material is not placed in a relevant context. Furthermore, there is no explanation of where the genetic material to fill these new cells comes from, because detail of DNA or DNA replication is not required. From cell division teaching typically leaps to the concept that chromosomes have genes, usually differing versions called alleles, and alleles for a common characteristic like eye colour are followed through individuals using punnet squares and heredity charts. The idea of genes not being switched on at all has no part in the curriculum so the idea of quiescent genetic material does not surface.

IMPLICATIONS FROM INTERVIEWS

The interviews reveal interesting tensions between the intuitive views of the individual and the scientific view. The tensions are between separation, the treatment of the organism as made up of small components, and integration where the organism is perceived holistically by children; between the similarities emphasised by the science view of stability in the genetic code and the differences in physical appearance perceived as more important by the child; between the somatic inheritance view of characteristics emphasised by children and the importance of the germ plasm emphasised by science; and between the emphasis on genes as structures from the children and the gene as a piece of information from the science view. These tensions are summarised in Table 1.

Overall the emphasis in science is that the similarities are much greater than the differences. This acknowledges that human beings, being one species, have huge genetic similarities. Indeed, the genetic differences between humans and the chimpanzee is relatively slight. In contrast the emphasis for the child is on differences from another individual. The interviews showed an oscillation by children between the need for reassurance that they are not oddly different from other humans and a need to maintain their individuality. This finding will be further investigated during the research.

TABLE 1
COMPARISON OF CHILDREN'S AND SCIENTIFIC VIEWS

	Views from interviews	**School Genetics view**
View of self	**Integrated** self seen as a whole, not divided up into small bits	**Separated** lots of small invisible bits that have functions
Similarities and differences	**Uniqueness** distinct differences between me and others of the same species, acquisition of characteristics in my lifetime to cause uniqueness.	**Commonality** Commonality of genetic code. Replication to ensure identical material in cells.
Gene expression	**Somatic** emphasis is on the physical appearance of individuals	**Germ plasm** emphasis is on the transport of information in the gametes.
Gene concept	**Structural** gene is like other physical structures within my body and responds to the environment.	**Informational** gene is fixed chemical information that provides information for structural development.

CHILDREN'S VIEWS AND THE PRESENT CURRICULUM

The Mendelian model within the school curriculum describes a very controlled, conservative system affecting a limited amount of genetic material within cells. A commonly used example of an human characteristic is eye colour. In the simplified explanations used in schools, eye colour is attributed to two alleles, blue and brown, which are attributed to a single gene. The genetic material will behave in a predictable fashion. For example, if you have parents with blue eyes then you will inherit blue eyes.

What the children observe is very different from this controlled, conservative model. Firstly, they observe a huge variety of eye colour besides blue. Secondly, there are instances where blue-eyed parents do not produce blue eyed children.

> Oh well, Mr Burgess told us a little while back that every gene is either dominant or recessive, or something, and if there is dominant and recessive the dominant will win and that might be darker hair colour or something. Oh, that is another thing, I have got brown eyes and my Dad has both green eyes and my Mum has got blue eyes............so that is a bit curious. **Boy 12 yrs**

Generally school genetics, Form 5 (Year 11) and below, does not dwell on concepts such as replication, where a cell makes a copy of its genetic material, apart from looking at the different stages of meiosis and mitosis , and it certainly does not explore concepts of regulating genes. There is some discussion of variability of expression, such as variation in height within a class, but this is not linked to the genetics. In fact, without the concept of regulatory genes, which are essential for making sense of what you actually see, it would be difficult for children to make the links between variation and gene expression. Nor does school genetics generally own up to the fact that eye colour, like many human characteristics, is actually polygenic, controlled by many genes, and that expression of eye colour is not the simple blue/brown picture that students are led to believe.

The concept of Mendelian genetics based on units called genes will only relate to 'real life' if a learner has a grasp of replication and the more complex interrelationship between regulatory genes, associated proteins and the expression of the gene. The whole characteristic package of an individual is a result of the expression of millions of genes. Individual characteristics are affected by those genes, out of a range of possible genes, which are actually switched on and working at any one time. The sheer size of the code guarantees that a characteristic will be expressed. For example, an individual develops a nose because enough genes are working to provide information for the construction by the foetus of a nose structure. However, the variable genes that are in 'on' mode create an unique shape to the nose in any individual.

The teaching of genetics in schools emphasises the genotype whilst the child builds her concepts around the phenotype. There is a need to find a balance between the stresses on similarity underlying school genetics and the stresses on difference coming from the individual. It is most important that children have an understanding of genetics 'under the skin' as this will allow them to make informed decisions about the genetic issues facing the community. As citizens, children have right of access to this knowledge. The research to date indicates that to develop this genotypic understanding, learning needs to be based on a phenotypic approach. Starting with the characteristics the students see and exploring the 'hidden' explanation for how the characteristics are created later.

In addition, there is a need to explore how students can be helped to see the gene as more of a source of information than as essential structure for a characteristics and that certain parts of the information are used to create structures that produce the phenotype of an individual.

INTERVENTION

The next phase of this research will be to devise an intervention that aims to develop the structural, phenotypic perspective into an understanding of the underlying process. The holistic perspectives of children suggests that the customary introduction to genetics using Mendelian punnet squares requires revision. Furthermore research into problems in genetics suggests that grappling with the mathematics of proportional genetics calculations may result in mathematical problems getting in the way of understanding of the underlying concepts of genetics.

Duckworth (1991) argues that we should keep it complex and that distilling an idea to its simplest form may not bring the enlightenment expected from a simplification. Certainly school genetics is one of curriculum's best example of 'keeping it simple' or at least simplified as it is distilled to a mathematical algorithm. Duckworth's work supports the idea that learners respond well to exploration within a complex context. There are plenty of complex contexts within genetics! In addition, if areas of interest for students are more successful for development of ideas there are a number of issues which are regularly aired in the media could prove fruitful learning experiences. Animal or plant breeding which emphasise the phenotype and reliable replication. Gene therapy and genetic engineering open up the whole area of complexity which would lead to exploration of important concepts at the level of the invisible bits which are so important for children to understand. This would allow them to make better informed decisions about the genetics issues facing society.

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Research in Science Education, 1993, 23, 345-346

ABSTRACTS AND RESEARCH NOTES

AN INTEGRATED SCIENCE PRE-SERVICE TEACHER TRAINING COURSE: A FOCUS ON ASSESSMENT.

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RESEARCH NOTE

All students undertaking science methods in the pre-service teacher training year at Monash University participate in an integrated science program known as Stream 3. This course has been developing for 15 years. The emphasis of the Stream 3 programme is to encourage pre-service teachers to take on responsibility for their own learning. The most recent innovation in this course is in the area of assessment strategies aimed at maximizing student learning by providing an integrated approach to assessment across method areas. These approaches are documented by students in a teaching portfolio. This paper describes some of these tasks and examine the implications for pre-service science education.

The Teaching Portfolio

In order to foster independent learning in our pre-service teachers so that they might do the same with their own students, a change in our approach to assessment seemed appropriate. We wanted students to learn from the assessment they undertook, and not just complete it as a hurdle along the way to getting their Diploma in Education. As a result, the notion of a *teaching portfolio* was developed. Teaching portfolios are tangible representations of what students see as their "philosophy" of teaching and learning in science.

The use of portfolios in the Stream 3 programme is intended primarily as a learning procedure that would also result in a final product that pre-service teachers could use with prospective employers. The process of preparing a teaching portfolio and refining it after receiving feedback allows students the opportunity to reflect on their own ideas and attempt to present them in a coherent way. The process is essential for the learning to occur. The end product allows pre-service teachers to present documentation to prospective employers that could provide important evidence in selection decisions. The product also provides a prospective employer with a starting point for discussion with the pre-service teacher. The discussion is much more likely to focus specifically on the abilities, views and skills of the pre-service teacher.

The purpose of the portfolio is for students to think about their philosophy of what it means to be a science teacher. In this case the development of attitudes and views is as valuable as the development of skills and abilities. The portfolio is designed to cover a range of tasks and activities that might reflect an individual's approach to science teaching.

To support the development of the teaching portfolios, students are asked to undertake a number of activities, including:

- interviewing students and teachers about teaching and learning;
- undertaking research, perhaps involving a research project, in a familiar or unfamiliar content area;
- preparing and experiencing aspects of Frameworks and VCE curriculum design;
- experiencing teaching in a diversity of styles incorporating a number of teaching strategies such as PEEL strategies or co-operative group work;
- preparing a media file of newspaper clippings, videos etc. for use in teaching science;
- demonstrating how they might plan, organize and conduct an excursion or site visit; and
- using various software programs in science education.

Researching the Teaching Portfolio Strategy

As a means of gauging this assessment approach, a small research project was set up to monitor students' views. A sample of eight students (out of 30) volunteered to participate in the research project. Participation required the students to be interviewed at three stages throughout 1993 by an independent interviewer. At the time of writing this paper only the first of three interviews has been undertaken.

One of the difficulties for the lecturers in this process has been trying to explain what a portfolio is to the students. The idea of the portfolio only becomes clear to the students as they actually undertake the tasks. When this is coupled with students' previous experiences of assessment from their own schooling and undergraduate careers where they have clear notions of what is expected in an examination or an essay, it takes a great deal of effort to get them to "do" the tasks first. It is only after trying out these tasks, obtaining feedback from their tutorial groups and reflecting on this feedback, that a clear picture of what a portfolio item might look like emerges.

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PROBLEMS WITH IMPLEMENTING SCIENCE AND TECHNOLOGY IN PRIMARY SCHOOLS IN N.S.W.

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RESEARCH NOTE

This study identified difficulties faced by primary teachers as they implemented a new curriculum in science and technology education in N.S.W. A survey instrument was tried out at two schools, and refined after consultation with twenty four primary teachers enrolled as a part-time students in a science education subject in a Bachelor of Education conversion course for non-graduate teachers. The sample consisted of a stratified sample of 15 state schools selected from a pool of 40 local schools. At the end of the project, science co-ordinators from surveyed schools were asked to comment about the reliability of the findings.

RESULTS

There were 32 male and 68 female respondents. The average number of years that they had been teaching was 17.6 (standard deviation 6.4). Forty nine had been teaching over 17 years and these figures are a typical age-profile of primary teachers in Australian (DEET, 1993). Forty seven percent of respondents were not graduates, and most of these had not updated their initial tertiary training. Interviews with teachers enrolled in the BEd conversion course revealed that recent changes in the criteria for teacher promotion led to their renewed interest in tertiary studies, because additional qualifications were perceived as a vehicle for promotion and increased salary.

Teaching science

No significant gender difference in the time allocated to science teaching was found. Teachers indicated that they spent an average of 45 to 60 minutes per week teaching science, i.e. less than 12 minutes per day; less than half of the time recommended for such a key learning area. Twenty percent of respondents were spending more than 12 minutes per day teaching science, and 13% were spending less than 5 minutes per day. A typical comment by a school science co-ordinator was "science like art, craft and music requires additional preparation time. Therefore teachers will avoid these subjects when pressed for time..." Teachers concentrated on science-based units and taught less of the designing and making, and technology sections of the syllabus. More females than males were collaborating to develop programs (teaching units), but overall, the amount of collaboration was low.

Support and assistance

Thirty percent of respondents felt that they were able to receive adequate advice and assistance. This indicates that there was an immediate need for teacher in-service. Ninety five percent of respondents considered that self-contained experimental kits would assist their teaching, and only five percent considered that booklets of stencil masters would be useful. Responses from interviews indicated that teachers wanted to employ a "hands on" approach to science but needed help with ideas and resources. Fifty one percent had received no in-service training at the time of the survey. The most popular suggestion was a one day in-service conducted during school time at a "host school" by consultants or local teachers. Most respondents (63%) also felt that these in-service courses should occur four times per year or once every term.

CONCLUSION

Although all teachers were spending some time on science teaching, most were teaching less than 12 minutes per day. Nearly 75% of teachers were implementing science units similar to those used in the past. This strategy gave them time to learn about other aspects of the syllabus and for sample units to be developed. All teachers interviewed indicated that they had little time to devote to their own in-service and needed help. This issue was raised by Cumming (1992, p.8) in his discussion about the need for "high quality professional development" for teachers who will implement a national curriculum. There is an immediate need for self-contained kits of materials. Ideally such kits should be in small portable containers and use items that are cheap, readily available and easy to use. Such kits are being developed by the National Science Centre in Canberra and are called "Exciter Packs." Teachers interviewed stated that finding and organising the materials required for science lessons took time that they could not spare.

Some important issues arising from this study that need to be considered by planners of primary science education are:

* teachers should, but do not always want to, allocate more time to the teaching of science.
* there is a need for regular in-service that is held in schools.
* support kits of "hands on" materials are needed by nearly all teachers.
* universities and secondary schools can provide of human and physical resources that could support the implementation of the syllabus.
* while the use of teachers to train their peers may be well received, there is a danger that they will be taken away from classes and their students will suffer. Also problems with over-commitment and "teacher burn-out" may also occur.
* making a section of a syllabus mandatory does not guarantee that it will be taught. Teachers avoid sections of the syllabus if they lack confidence.

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THE ROLE OF GROUP WORK USING COMPUTATIONAL EXPLORATORY LEARNING ENVIRONMENTS WITHIN CHILDREN'S LEARNING IN SCIENCE

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RESEARCH NOTE

The study focuses on the development of pupils' cognitive strategies while using computational exploratory environments (the various problem-solving activities which pupils have undertaken provide opportunities for the development of particular skills connected with problem-solving, investigation and reasoning skills) and on the effects of group work (based on how the group functioned, the motivation and involvement of pupils, how these environments influenced pupils working together and vice-versa). The results of the study were drawn from appropriate observations, interviews and questionnaires from 90 pupils aged 10-13, from junior and secondary schools during the application phase of their learning process in Science topics and are mentioned below.

The creation of a HyperCard stack can be a creative and communicative form of learning, lending itself not only to the development of computer and science skills but also to the extension of the child's language. However, for the purpose of this study, it is the problem-solving aspect which takes precedence. The various activities which pupils undertook by creating HyperCard stacks provided opportunities for the development of particular skills connected with:

- **Problem-solving** (deciding upon or identifying a problem; planning strategies, carrying them out, and recognizing whether they are successful and where they are not; checking solutions, relating them to the original problems, and deciding how reasonable they are; revising and redrafting; self-evaluating).

- **Reasoning** (reasoning logically; drawing inferences; being systematic and consistent; describing and explaining methods, reasons, strategies, predictions, results or conclusions).

- **Investigation skills** (asking questions and deciding which of them to pursue; making hypotheses; setting up fair tests; monitoring: continuous attempt to match efforts, answers and discoveries to initial questions or purposes; classifying: identifying properties, similarities and differences; counting possibilities; recognizing patterns and relationships).

The important skill of decision making is not listed separately since it is implied in many of those which have been described.

Groups of students began by talking among themselves and exchanging ideas on how to present the topics to other users. Then they decided on the plans, the distribution of work among them and the timetable. Thus, the creation of a HyperCard stack contributed to the pupils' personal and linguistic development, as well as providing a stimulus for the growth of problem-solving skills. A problem-solving situation is set up by offering a task which requires interpretation through the creation of a stack.

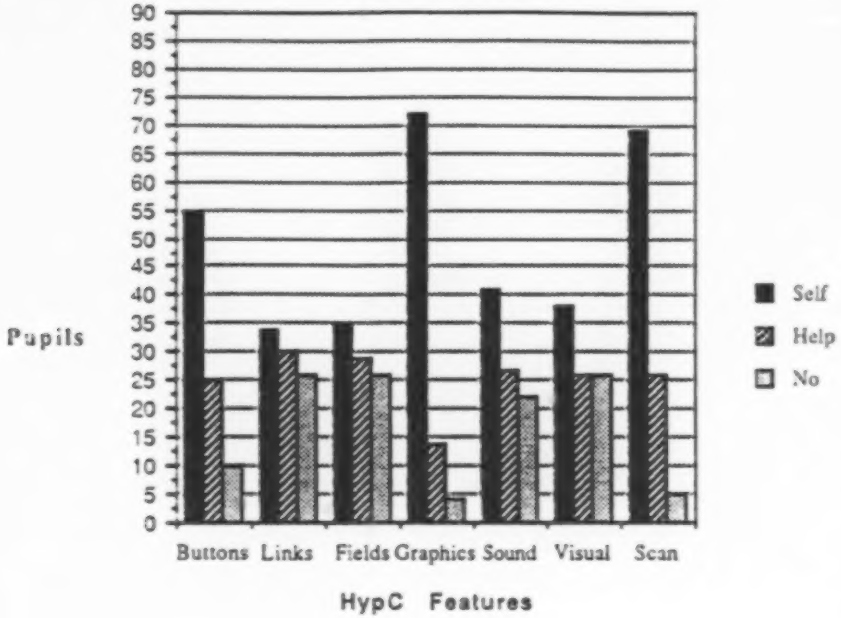

Fig. 1 HyperCard features created by pupils

Fig. 1 shows some of the findings of the study. In this figure, '**Self**' means that pupils created the HyperCard feature by themselves; '**Help**' means that they created that feature with some help from other classmates or their teacher; '**No**' means that they did nothing with that feature. The figure shows that the majority of the pupils created buttons, graphics and scanned pictures by themselves. Many pupils also created sounds and visual effects by themselves. Some of them created links and fields by themselves.

The majority of pupils enjoyed working with HyperCard in groups although the work was hard because of its technical competence. Concerning the distribution of work, all pupils worked taking turns most of the time. Mutual help among them was observed. Additionally, teachers' strategies were pupils' monitoring, pupils' encouragement, being a facilitator/guide for learning and for group work.

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LEARNING IN SCIENCE CENTRES AND SCIENCE MUSEUMS: A REVIEW OF RECENT STUDIES

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RESEARCH NOTE

School visits to science education centres and science museums (SECSM) often result in children armed with worksheets rallying from exhibit to exhibit in a search for knowledge. It is assumed that learning occurs. Does it? Investigations into cognitive, affective and psychomotor learning in these settings have resulted in a variety of conclusions. A review of recent studies in the science education centre and science museum settings that investigates student or visitor change in science content knowledge or attitudes towards science has been compiled from a wide range of literature. The rapid growth of SECSM and their impact in promotion of science to the public has resulted in more science education researchers devoting research to this important setting outside of the classroom or school science laboratory. Many teachers utilise the resources of SECSM in their teaching with class visits to SECSM. These field trips are enjoyed by many children who attempt to engage with as many exhibits and activities as possible, with some children rallying from exhibit to exhibit. Education researchers have used a variety of instruments and methods to investigate students' or visitors' change in science content knowledge or attitudes towards science. From a comprehensive review of literature research, a number of studies (n=38) have been identified which are concerned with cognitive, affective and psychomotor learning. The studies have been classified into groups according to the method of research technique and the specific purpose of the research. These categories are: (a) cognition studies, (b) group interactions, also referred to as child-adult interactions; (c) impact of SECSM on school groups, (d) impact of SECSM on docents, (e) impact of SECSM on visitors, and (f) evaluation studies. Each paper has its results summarised and the research procedure is described and discussed.

The purpose of the review was to gain insight into the techniques of the researchers who investigate children's learning in the informal education setting of SECSM. Many of the studies reported are published in journals, monographs and limited circulation periodicals not associated with education or science education. These obscure publications include museum journals, visitor studies journals; monographs and restricted publications of science museums, science education centres, science and technology centre associations, museum associations and visitor study associations. In addition, a small group of research studies are undertaken as private reports to fulfil the requirements of government audit guidelines for museum performance and are not published. This review and classification would be of use for science education research in SECSM of Australia. Some of the articles are available from Australian SECSM library collections. A wide range of methods are reported and the findings of the studies show a range of differing outcomes for children and adults who visit SECSM.

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Research in Science Education, 1993, 23, 352-354

STUDENTS' AND TEACHERS' EXPLANATIONS OF CHEMICAL EQUILIBRIUM

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RESEARCH NOTE

This research note reports on a preliminary exploration of the verbal explanatory frameworks provided by teachers as the bases for instructional units on the topic of chemical equilibrium. This pilot analysis seeks to describe and explore qualitatively (i) the language and types of explanations used by teachers during sequences of lessons and (ii) the types of responses given by students to structured hypothetical questions in one-to-one interviews. The words and phrases inherent in the explanations used by teachers and students in the initial analysis are currently being used as the basis for a computer-aided content analysis of a larger sample of 54 verbatim lesson transcripts.

Method

Six Senior Chemistry teachers and their students from four independent schools in Brisbane were voluntary participants in this study. Complete three-week sequences of lessons on the topic of chemical equilibrium were audiotaped and verbatim transcripts prepared. Seventeen students of varying achievement levels from three of the schools were nominated by their teachers and agreed to be interviewed about their understanding of chemical equilibrium. Thus, two data sources have been examined to date: 27 verbatim lesson transcripts obtained from three classrooms during the teaching of a unit and 17 transcripts of individual structured interviews with students.

Types of explanations

Ten types of teacher explanations were identified by Dagher and Cossman (1992) and these have been used to categorise explanatory episodes in the lesson transcripts. The following quotes drawn from the text of the transcripts illustrate the four most frequently used explanation types.

> Let us see what we can deduce from our observations? Let us look at the equation for the formation of the complex $(FeIISCN)^{2+}$. Look at the first step of this experiment — we can identify the colours of this species.......... (Rational)
>
> You can explain Le Chatelier's Principle if you use the collision theory, that if you have more of those to collide with these, therefore the collisions between hydrogen ions and acetate ions will occur more readily, more frequently. (Mechanical)
>
> So the Fe^{3+}, because it has gone up, will try to reduce it and the only way it can is by combining the thiocyanate ion and moving it in the direction of this red complex. (Anthropomorphic).
>
> If you dropped the temperature, that is like taking heat away from this, the reaction will shift in the direction in order to regain equilibrium. (Teleological).

Variation between three teachers

Examination of the language used by three teachers (identified by pseudonym) revealed marked individual differences in the frequencies with which they gave rational, mechanical, anthropomorphic and teleological explanations. As well, the frequencies of particular types of explanations varied with the focal activity in the lessons.

In the transcripts examined, Kevin gave mostly mechanical explanations and referred to theory in the textbook as the basis for those explanations. Discussion of demonstrations was oriented to confirmation of theory rather than deduction from observation. Embedded within nearly all his references to shifts in equilibrium position and to Le Chatelier's Principle was anthropomorphic language, e.g. the system "tries to get back to equilibrium."

William emphasised the development of rational and mechanical explanations at the molecular level. Students were encouraged to make deductions from observations and to derive theory from experiment. He cautioned students against using anthropomorphism and frequently asked students to rephrase anthropomorphic statements or questions with implicitly mechanical language that referred to collision theory.

In Kerry's classroom the distribution of different types of explanations was apparently influenced by the context of the lesson, with considerable emphasis placed on the derivation of theory from observation. Much of the theory of the unit was developed through teacher/student discussion of observations made during demonstrations and laboratory exercises. Rational and mechanical explanations were predominant throughout the sixteen lessons. Anthropomorphic and teleological explanations were given infrequently and those occurred in lessons in which previously completed exercises and problems were being discussed.

Students' explanations

Transcripts of structured interviews with seventeen students from four classes also revealed variation in type. An interview protocol was designed in which initial questions established that an equilibrium reaction ($2X + Y_2 <--> 2XY$) was taking place in a closed vessel. Students were asked to predict changes in the direction of the reaction with addition of reactants or product and then to explain the basis for their prediction. If the student's response to the question was unclear the interviewer prompted the student with a series of remarks which escalated in degree of directiveness, e.g. "Could you explain that?" or "Could you give me more details?" through to "Could you explain what is happening at the molecular level?" and finally "What would happen to the probability of collisions between particles?"

There was a noticeable tendency for students to change the type of explanation with interviewer prompts, from initial anthropomorphism to a mechanical response. After prompting, many students gave mechanical explanations, but initially tended to use anthropomorphism or teleology as a convenient "chemical colloquialism," e.g.

> Student: Umm, they're doing it, in order to reach equilibrium because it's out of proportion if more of something is added. (Teleological).
> Interviewer: When more of something is added, what does it do to the relationships between the atoms and molecules?
> Student: How do you mean?
> Interviewer: Well, if you add more X, does it change anything?.
> Student: Um, yes. There's a higher probability of collisions between X and Y and therefore the forward reaction happening. (Mechanical).

Summary and Implications

The initial analysis of the lesson transcripts of three teachers has revealed that the balance of types of explanations differed between individual teachers. Within the classrooms of individual teachers, explanations also varied with the task that was the focus of the lesson. In the structured interviews, types of students' explanations varied with prompts by the interviewer. The distribution of types of explanation differs from that reported by Dagher and Cossman (1992).

Given the claim (Gabel, Sherwood & Enochs, 1984; Gabel, Samuel & Hunn, 1987) that ability to conceptualise at the molecular level is a key element in problem solving in chemistry, it will be important to investigate fully the influence of the language of explanation on the construction by students of their own personal models. For students who have acquired an explanatory framework consistent with the scientific view, and who are able to explain phenomena and events at the molecular level in terms of collision theory, the use of convenient phrases with implicit anthropomorphism such as "it will want to go the other way," may be a convenient shorthand. Whether the use of such language (with and by students holding partial or naive models) constrains the construction of more functional models is open to future investigation.

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Research in Science Education, 1993, 23, 355

GIRLS, BOYS AND CONCEPTUAL PHYSICS : HOW SENIOR SECONDARY STUDENTS HAVE RESPONDED TO A CONCEPTUAL PHYSICS COURSE

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ABSTRACT

This paper presents an evaluation of the Physics course at Dickson College (ACT). It highlights students' expectations before the course, and their impressions and feelings during the course. This is the second evaluation carried out as part of a long term study of student attitudes before and after the introduction of a more 'conceptual' approach to the teaching of physics at this college. Overall, this approach has produced a more positive attitude in all students, but more significantly in girls.

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